NEW

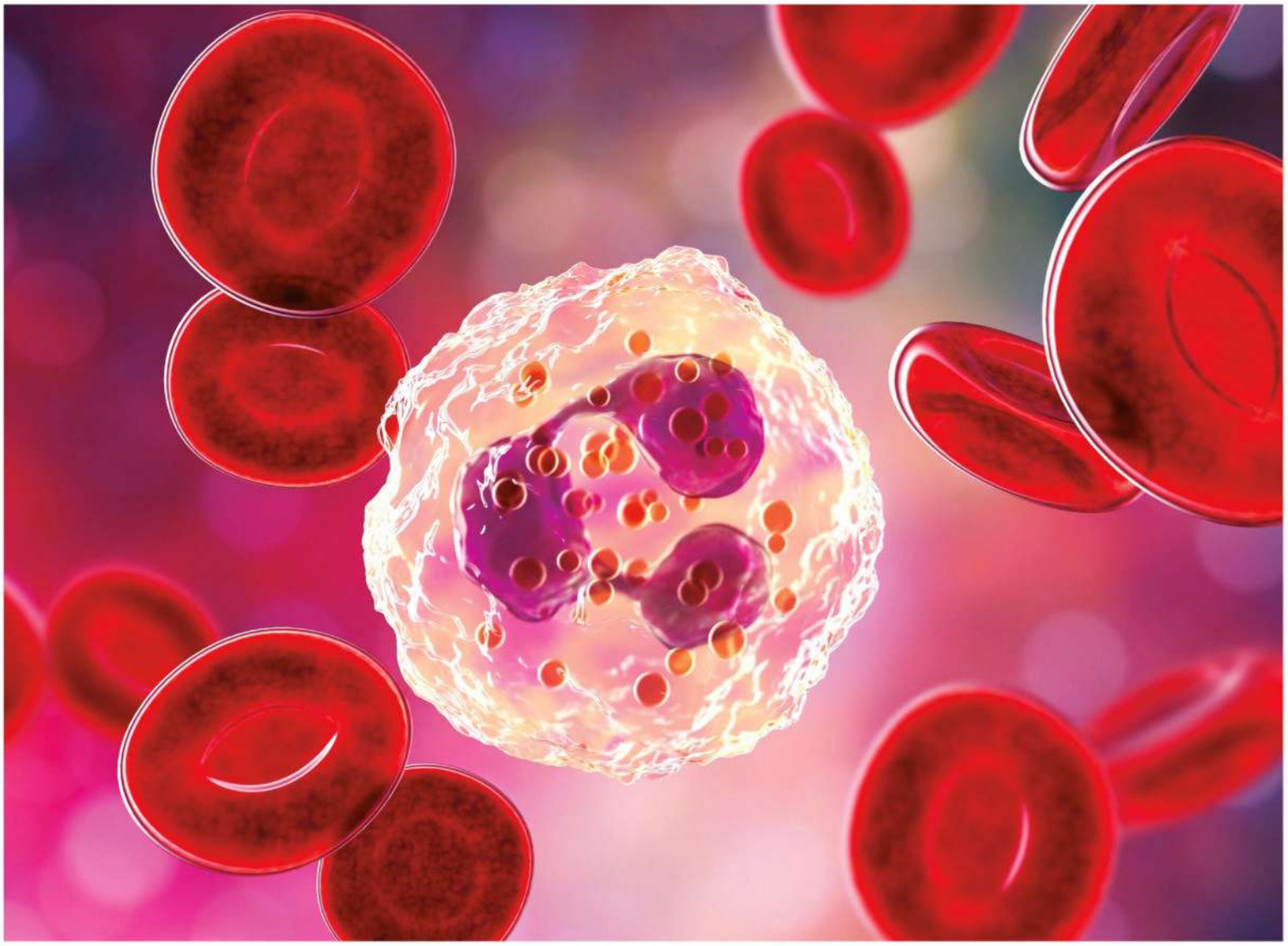
UNDERSTANDING Human Anatomy

PHYSIOLOGY
BIOLOGICAL PROCESSES
CELLULAR FUNCTIONS
NEUROTRANSMITTERS
ORGAN SYSTEMS
MEDICAL SCIENCE

Digital Edition

FUTURE

SECOND EDITION



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Welcome

Despite experiencing them first hand, human bodies never ceases to fascinate us. In this brand-new special edition, we've compiled a selection of articles from the *How It Works* archives as well as brand new features to explain the complexities of our own anatomy. Find out what we are made of, from the smallest cells to the largest organs, and how each and every element works together to create complex systems and what makes us, well... *us*. Discover what can go wrong, how modern science can fix it and how much more we still have to learn about our incredible bodies.

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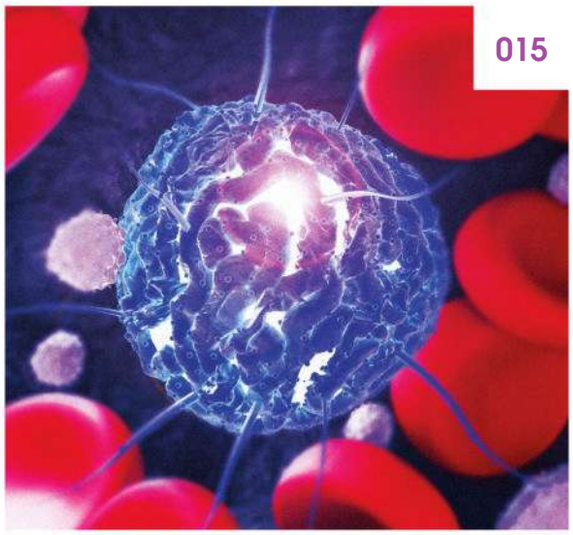

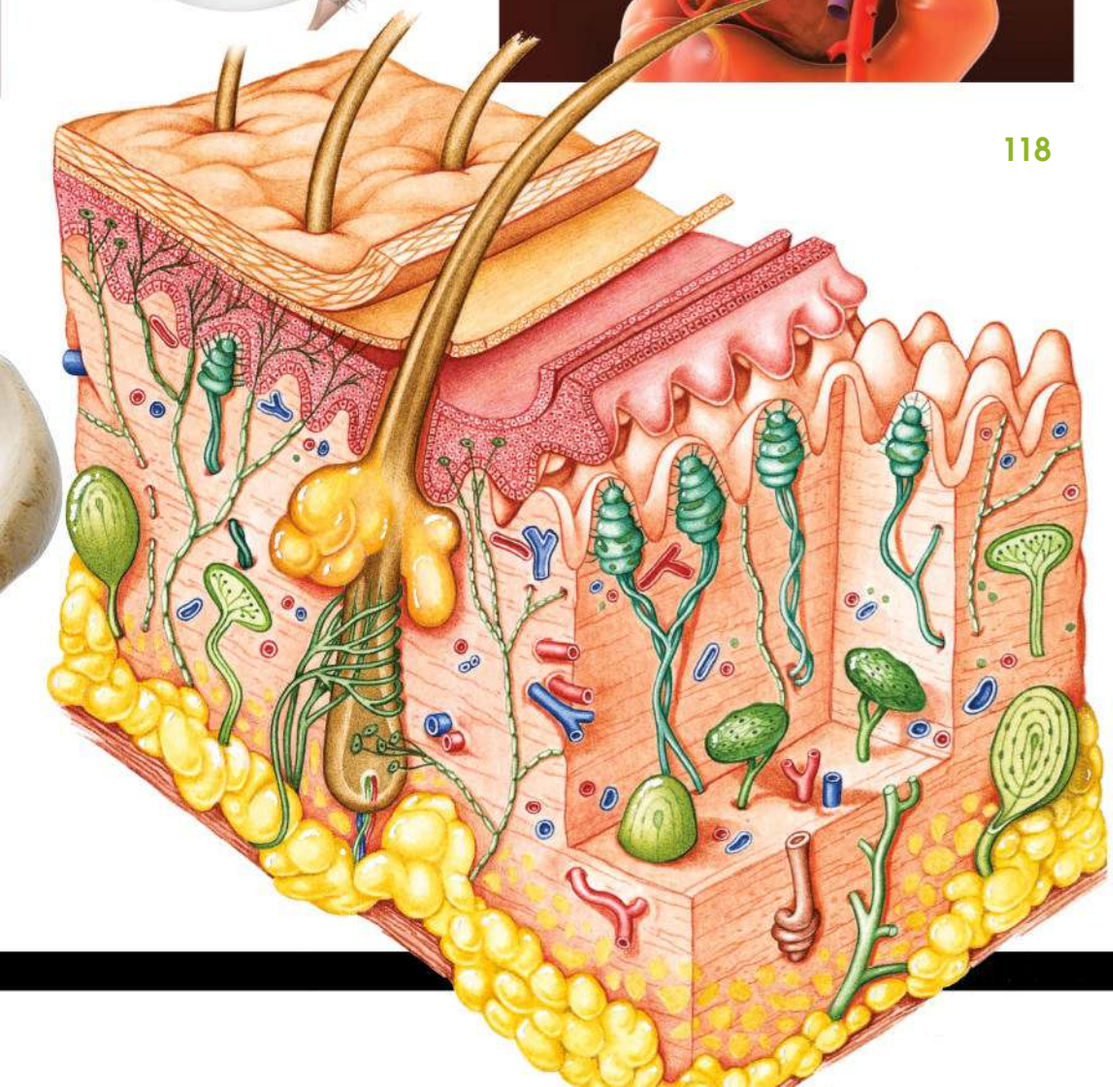

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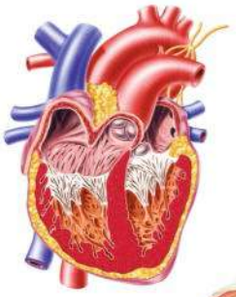
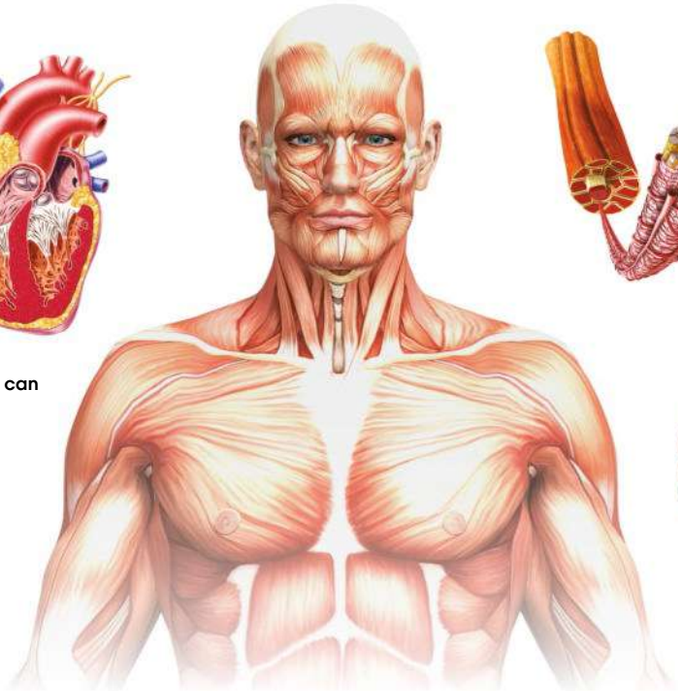
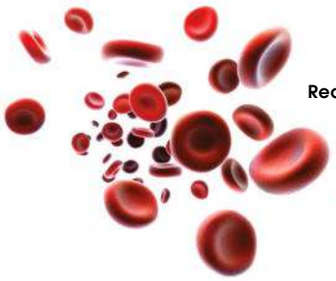
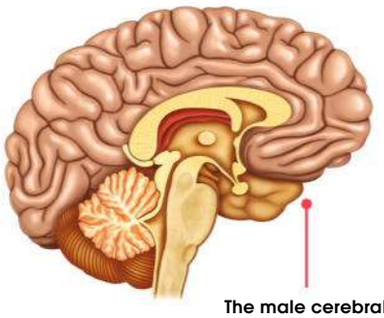
Making connections
The hyoid in the neck is the only bone that isn't connected to another bone



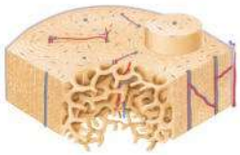




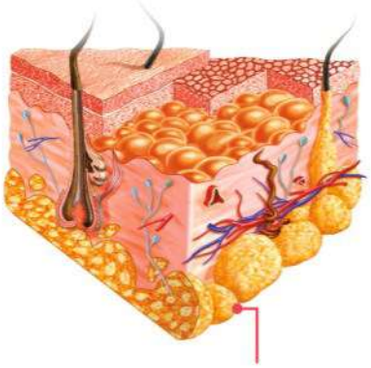
Red blood cells can live for up to 120 days



The male cerebral cortex has about 23 billion neurons



The body comprises around 75 trillion cells



1cm² of skin can contain 70cm of blood vessels

The human body

Journey inside the body to discover just what we are made of

The human body is composed of an estimated 7 octillion atoms, making up over 75 trillion cells. At the atomic level, the human body comprises about 60 elements, but the function of many of them is unknown. In fact, 99 per cent of the human body is made from just six elements.

Like all other life discovered to date, we are carbon-based; the biomolecules that make up our bodies are constructed using frameworks of carbon atoms. Carbon is almost unique among the elements; it is small in size and can make four covalent bonds to other atoms, allowing it to form the backbone of key molecules that make up the human body. The bonds are strong enough to hold the molecules in a stable structure, but not so strong that they can't be taken apart again, allowing the body to break and reform molecules over and over.

Calcium is the most abundant mineral in the human body, important for the regulation of protein production and activity.

Complex cascades of chemical reactions occur within the gel-like cytoplasm and organelles of cells – tiny structures that perform specific functions within a cell. Phosphorus is used to make adenosine triphosphate (ATP), which has high-energy phosphate bonds that can be broken in order to power cellular processes; ATP is essentially our cells' fuel. Cells are coated in receptors and respond rapidly to environmental changes, communicating via chemical signals and electrical impulses. During embryonic development, chemical gradients tell developing cells where to go, and what cell type to become, resulting in a new person.

Interestingly, the majority of the cells in the human body are not human. Microbes make up between one and three per cent of our body mass and are hugely important for our proper functioning. They have 8 million different coding genes for making proteins, compared to less than 30,000 in the human genome.

How many hairs?
A human head has an average of 100,000 to 150,000 hairs

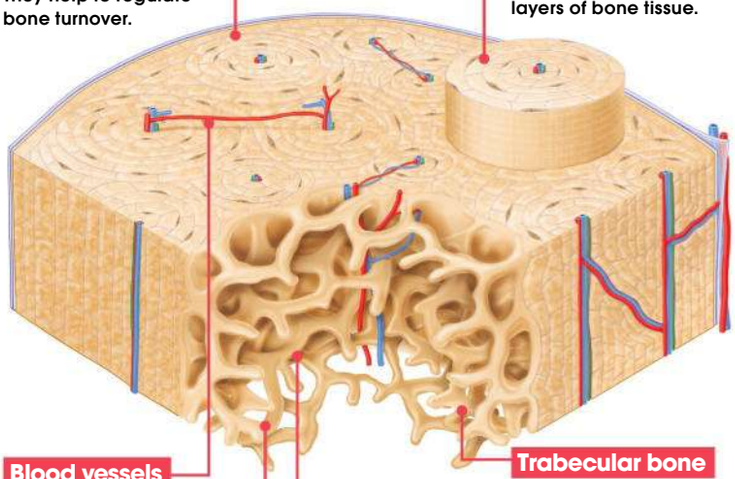
The bacteria that live in our digestive system provide essential support, too; they ferment undigested carbohydrates, allowing us to access energy we couldn't otherwise digest, and they have a role in the production of biotin and vitamin K. Their presence in the gut also prevents 'bad' bacteria from taking hold and making us unwell. Even more unusually, at least eight per cent of the human genome is viral in origin. Retroviruses are able to insert their DNA into our chromosomes, and at several points in human evolution, genes that started out in viruses have become permanently entwined with our own genetic information.

The structure of bones

The long bones of the body, such as the femur (thighbone), contain two distinct types of bone

Osteocyte
The cells that form the bone matrix eventually become trapped in it. They help to regulate bone turnover.

Cortical bone
The tough outer layer of bones contains densely packed cylindrical structures – osteons – formed from concentric layers of bone tissue.



Blood vessels
Bone is a metabolically active tissue and a good blood supply allows for mineral exchange.

Trabecular bone
Within the ends of long bones is a looser, honeycomb structure, where calcium is released from storage as required.

Osteoblast
Osteoblasts make new bone, producing the collagen scaffold and laying down minerals.

Osteoclast
Osteoclasts are related to cells of the immune system and digest old bone to release minerals and allow for remodelling.

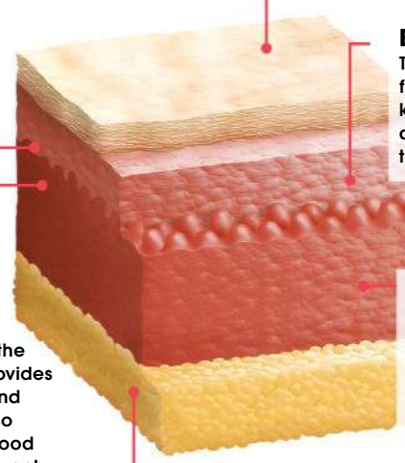
Beneath the skin

Skin has several layers with a unique function.

Largest organ of the body
The skin of a human adult measures two square metres (22 square feet)

Stem cells
A layer of stem cells at the base of the epidermis divides to form new skin cells, which push upwards to replace the dead ones.

Cornified layer
The very outer layer of the skin consists entirely of flattened, dead cells. These provide a protective barrier.

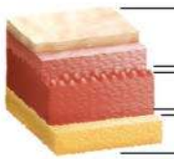


Epidermis
The outer layer of skin is formed of cells known as keratinocytes. These cells arrange in a multilayered tile structure.

Dermis
Connective tissue below the epidermis provides cushioning and support. It also carries the blood vessels that supply the skin cells.

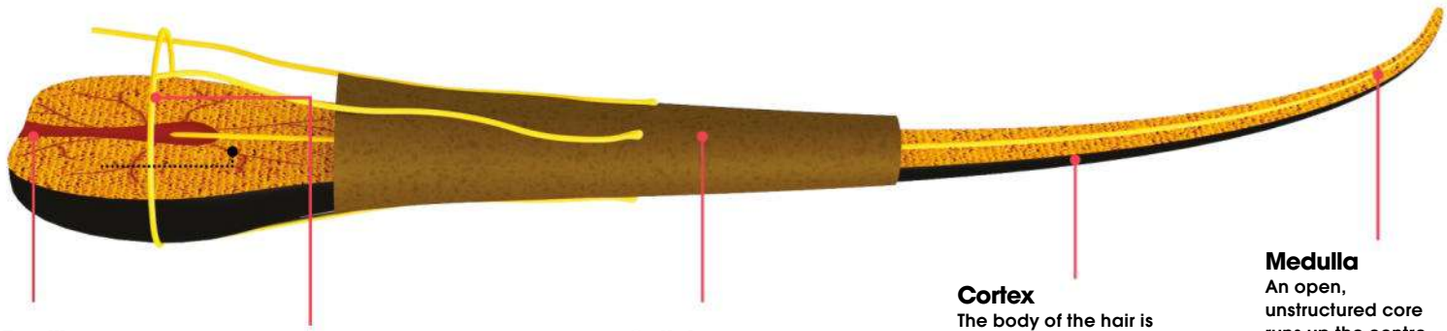
Papillae
The bumpy structure between the dermis and epidermis helps to anchor the two layers together, preventing them from slipping.

Fat
A layer of subcutaneous adipose tissue provides cushioning and insulation, as well as energy storage.



Hair under the microscope

A strand of hair can be divided into three distinct regions



Papillae
Blood vessels supply nutrients to the cells of the matrix and root.

Matrix
Cells of the matrix divide to produce new hair.

Cuticle
The outside of the hair is made of layers of flattened cells that overlap, protecting the hair.

Cortex
The body of the hair is made from coiled strands of keratin. Melanin granules within the cortex lend it its colour.

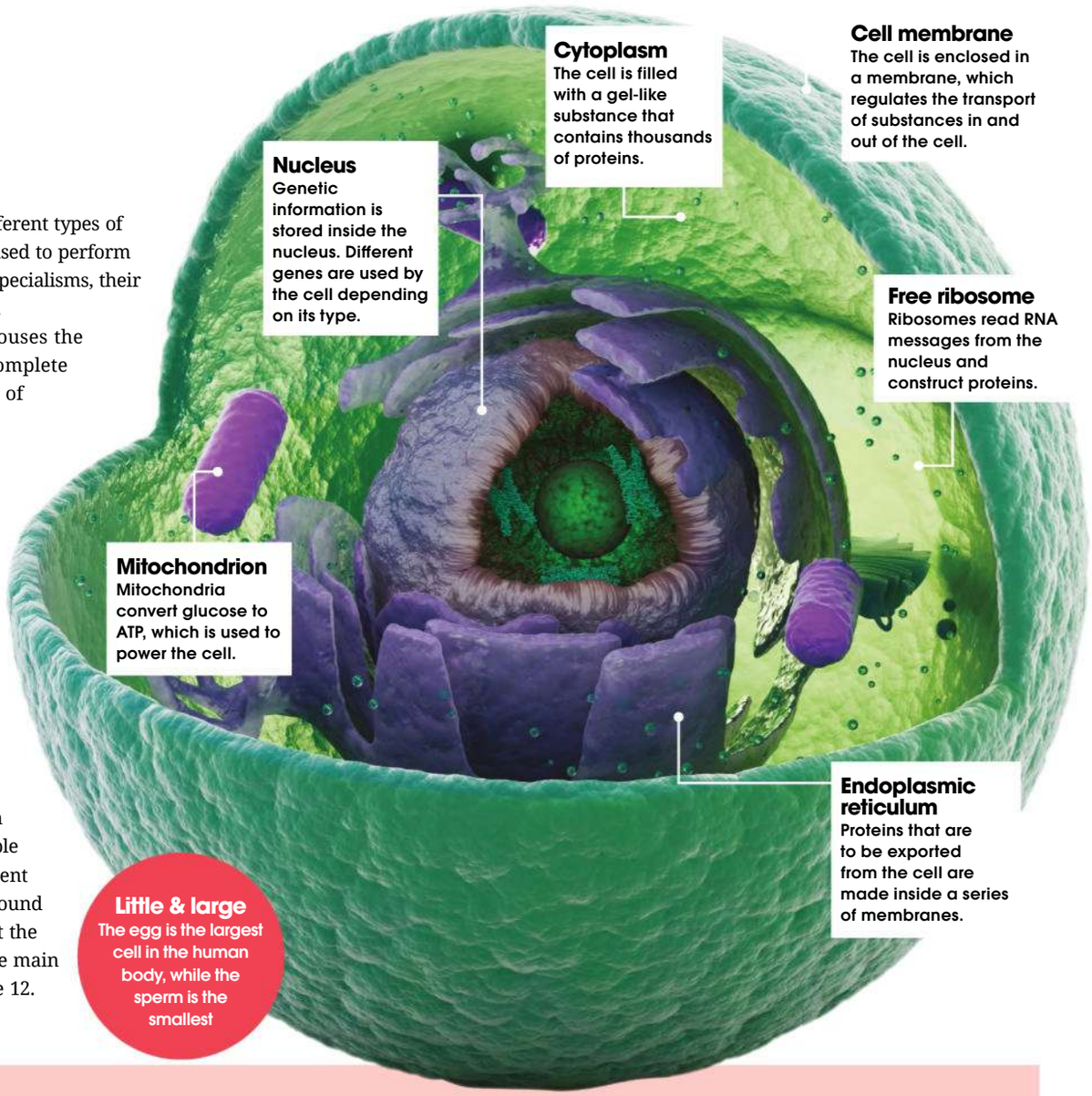
Medulla
An open, unstructured core runs up the centre of the hair.

Close up with cells

There are thought to be over 200 different types of cell in the human body, each specialised to perform a particular function. Despite these specialisms, their basic underlying biology is the same.

Cells contain a nucleus, which houses the 46 chromosomes, containing the complete set of instructions to synthesise all of the proteins found in the human body. Depending on the type cell, different genes are switched on and off, determining which proteins the cell will produce.

Proteins for use inside the cell are created on ribosomes in the cytoplasm. The ribosomes read the genetic message and assemble the corresponding protein using amino acids as building blocks. Proteins to be exported from the cell – for example, antibodies or digestive enzymes – are constructed within a series of membranes. Here they gain a number of modifications that enable them to survive the harsh environment when they leave the cell to travel around the body. For a more detailed look at the structure of human cells, some of the main types and what they do, turn to page 12.



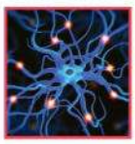
Little & large
The egg is the largest cell in the human body, while the sperm is the smallest

Key cells of the body

Blood and immune cells
Type: Blood
The cells of the blood, including red blood cells and the white blood cells of the immune system, are all produced in the bone marrow. Red blood cells lack a nucleus, enabling them to pack more of the oxygen-carrying protein, haemoglobin, into their cytoplasm.

Epithelial cells
Type: Skin and membranes
The cells that cover our bodies and line our body cavities form junctions with one another. Using proteins anchored between their membranes, they join to create strong barriers to protect the body.

Contractile cells
Type: Muscle
These cells contain a protein ratchet system, which enables them to contract. Actin and myosin form long strands, which slide past one another, pulling the edges of the cell together.



Nerve cells
Type: Brain and nerves
Nerve cells have specialised membranes, which use molecular pumps to maintain an electrochemical gradient; this allows them to transmit electrical signals. Nerves function more efficiently if they are insulated and many nerve cells are covered by a fatty sheath of myelin.

Stem cells
Type: Undifferentiated
Stem cells are ones that have not yet committed to a particular specialism. They are found in many locations and provide a replicating reservoir of cells that can be used to maintain and repair the body.

Extracellular matrix cells
Type: Connective tissue
The cells of the body are supported by networks of fibres including collagen and elastin. These are generated by extracellular matrix cells like fibroblasts, which produce and secrete precursor components that then assemble into the fibres that make up the matrix.

Endocrine cells
Type: Hormones
These cells generate hormones and release them locally or into the bloodstream. Their hormone-releasing activity is controlled by neurotransmitters sent from local nerves, or by other chemical messengers, which bind to receptors that are on the cell surface.

Germ cell
Type: Reproductive
Sperm and egg cells have just one copy of each chromosome and are formed by a special type of cell division called meiosis. When sperm and egg combine, the resulting cell has a full set of 46 chromosomes.

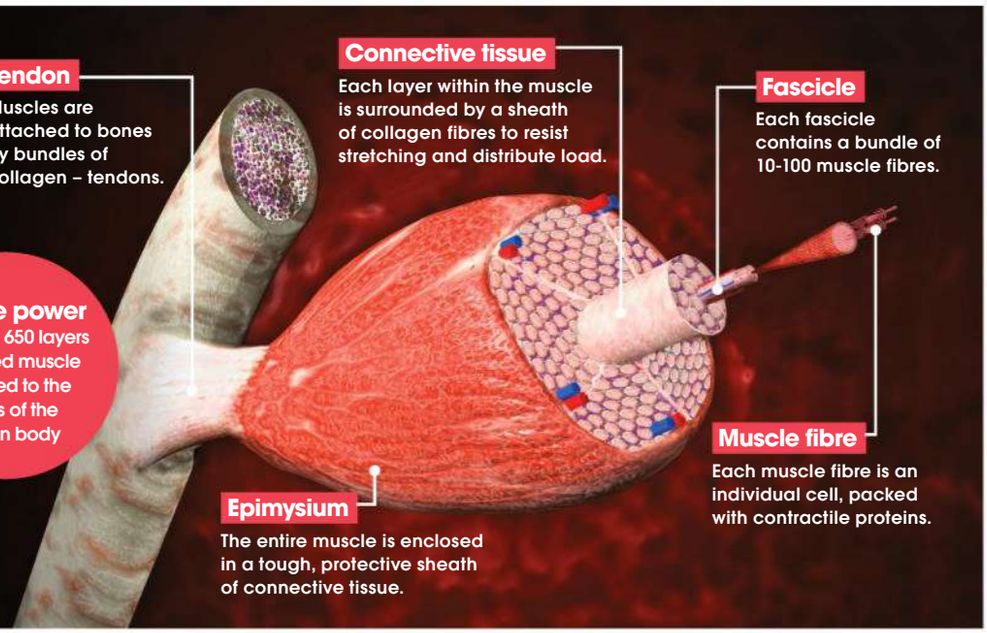
Muscle and movement

Skeletal muscle is responsible for moving the skeleton. It is composed of bundles of muscle fibres, sheathed in a strong collagen matrix, which extends into tendons that attach to the bone.

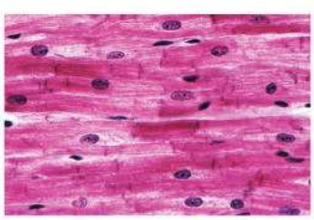
Within each muscle fibre is a molecular ratchet system made from the proteins actin and myosin. As the protein filaments slide past one another, the muscle fibre contracts lengthways and the fibre shortens.

Muscle fibres can be categorised as being either fast or slow twitch. Fast-twitch fibres use high-speed anaerobic respiration to produce rapid movements, but fatigue quickly. In contrast, slow-twitch fibres use sustainable aerobic respiration to produce slower movement for longer periods of time.

The proportion of slow- and fast-twitch fibres affects athletic performance – for instance, long-distance runners have a higher proportion of slow-twitch fibres than sprinters. Whether muscle fibres can change from one to another is under investigation.



Types of muscle



Cardiac muscle

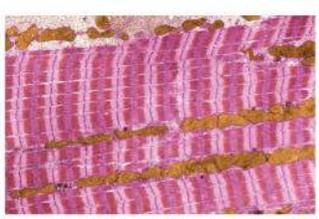
Type: Heart

Like skeletal muscle, cardiac muscle is striated. Connections between the cells allow the contraction to pass in a co-ordinated wave across the heart.

Smooth muscle

Type: Involuntary

The smooth muscle that lines internal structures is more elastic than skeletal muscle, allowing the intestines and bladder, etc, to contract even when stretched.



Skeletal muscle

Type: Voluntary

Skeletal muscle is responsible for moving the skeleton. Under the microscope it has characteristic striped bands, representing the contractile components within the cells.

A fatty fact

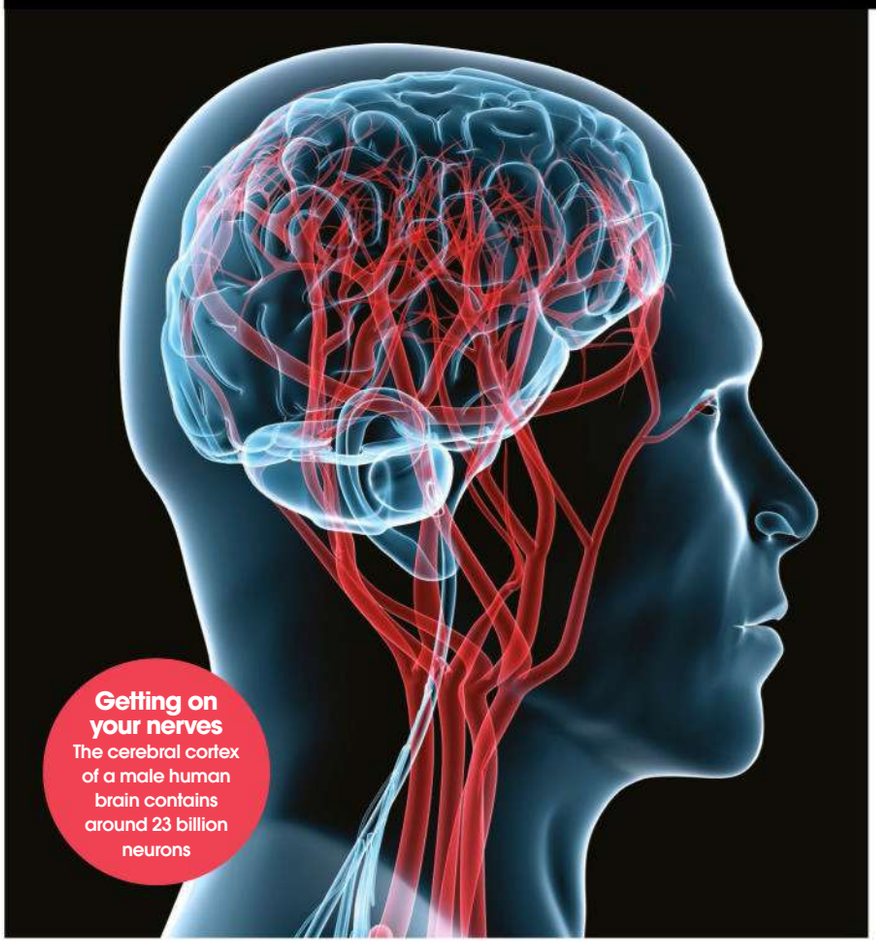
The average human adult will have 30 billion fat cells

Why our bodies need a little fat

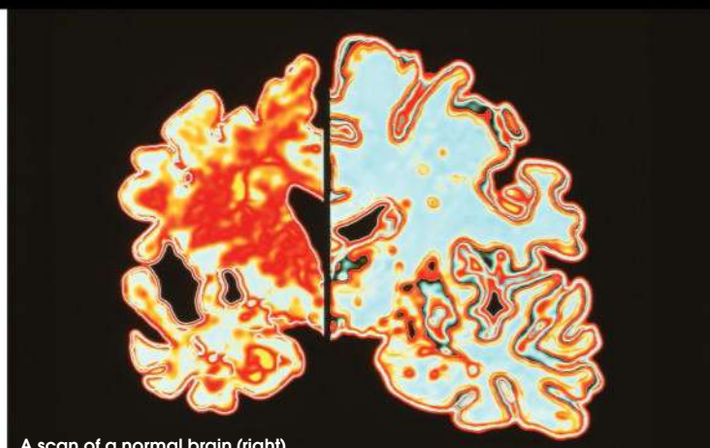
Adipose tissue provides the body with an energy reserve and also acts as a shock absorber – particularly on the soles of the feet. The fat cells – also known as adipocytes – contain a large lipid droplet, which takes up almost their entire volume, while their nuclei and other organelles are squashed on the perimeter.

Adipocytes are not just used as storage sacks, though. They have important metabolic and hormonal duties, too, including involvement in the production of oestrogen.

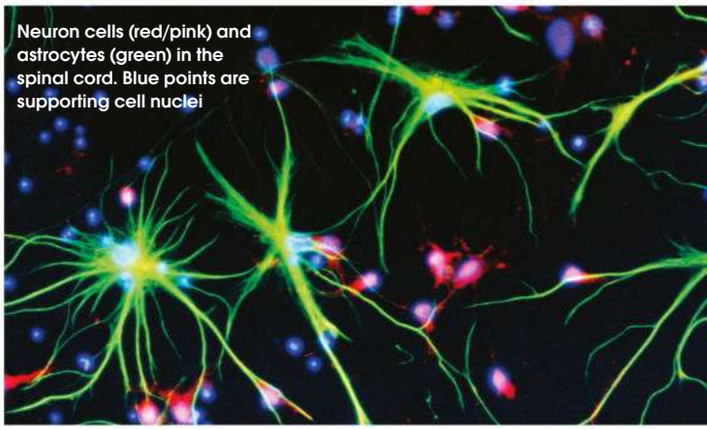
Humans have a second type of fat tissue known as 'brown fat'. More commonly found in infants, brown fat provides a thermal blanket around the neck and the major blood vessels in the thorax. Brown fat cells are able to generate heat by a method known as uncoupling; instead of using glucose to make energy for the cell in the form of ATP, the brown fat can release the energy as heat. This is thought to be very important in newborns, who lack the ability to keep warm by shivering.



Getting on your nerves
The cerebral cortex of a male human brain contains around 23 billion neurons



A scan of a normal brain (right) and another with Alzheimer's (left)



Neuron cells (red/pink) and astrocytes (green) in the spinal cord. Blue points are supporting cell nuclei

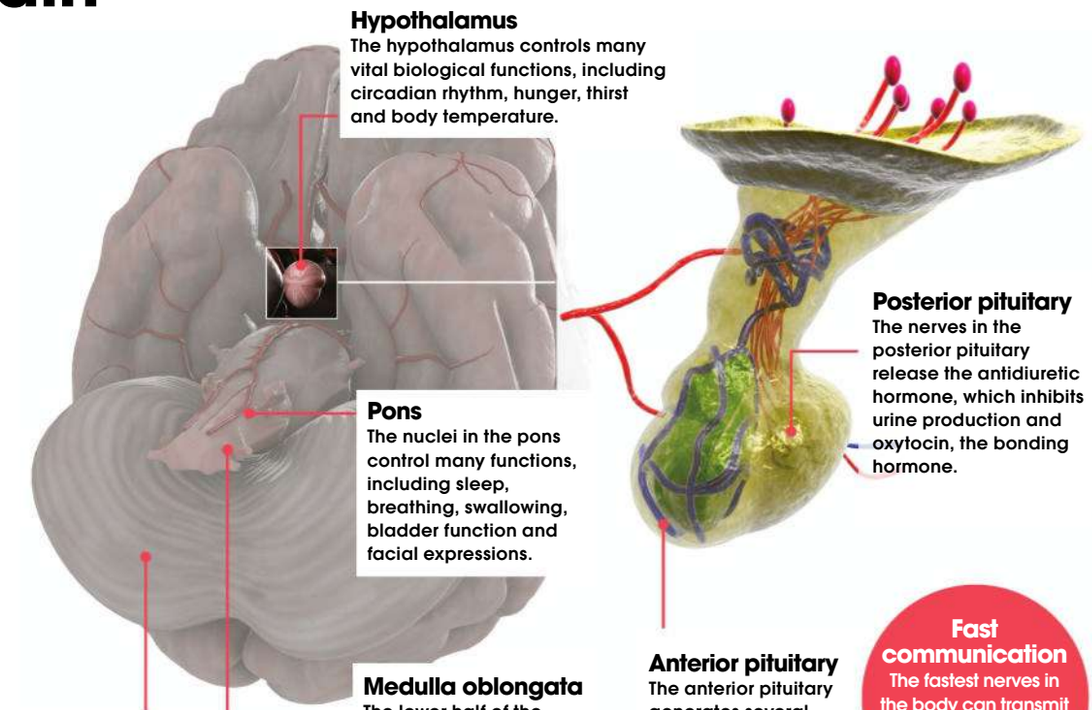
Inside the brain

The brain is made up of two major types of cells: neurons and glial cells. The neurons of the brain are highly specialised cells, interconnected by long, branching processes. They communicate through electrical 'action potentials', which can travel along the axons at speeds of one to 100 metres (3.3-328 feet) per second.

When an action potential reaches the synapse at the end of a nerve, it triggers the release of chemical transmitters, which bind to receptors on neighbouring nerves. Depending on the combination of neurotransmitters released – and the timing – the target nerve will fire, propagating the signal through the brain.

Glial cells, on the other hand, provide support to the neurons and have a variety of specialist functions. Astrocytes help to take up excess neurotransmitters from synapses, preventing neurons from damage due to excessive stimulation, while oligodendrocytes form fatty sheaths in order to insulate nerve cells in the brain and spinal cord.

The brain has significantly more protection than the other organs of the body. It is shielded from mechanical stress by the thick bones of the skull and is suspended in a cushion of cerebrospinal fluid. At the microscopic level, the brain is protected from potential hazards in the bloodstream by the blood-brain barrier – the cells lining the capillaries are joined together by tight junctions, controlling the passage of all molecules and bacteria into the organ.



Fast communication
The fastest nerves in the body can transmit electrical signals at 120m (394ft) per second

The ageing body

We may not be able to stop it, but we can begin to understand it

The human body changes as it ages, and the peak time for organ functionality is thought to be around the age of 30. The body has amazing capacity for regeneration, but cells can only divide a finite number of times, and as we get older our ability to repair damaged tissue decreases.

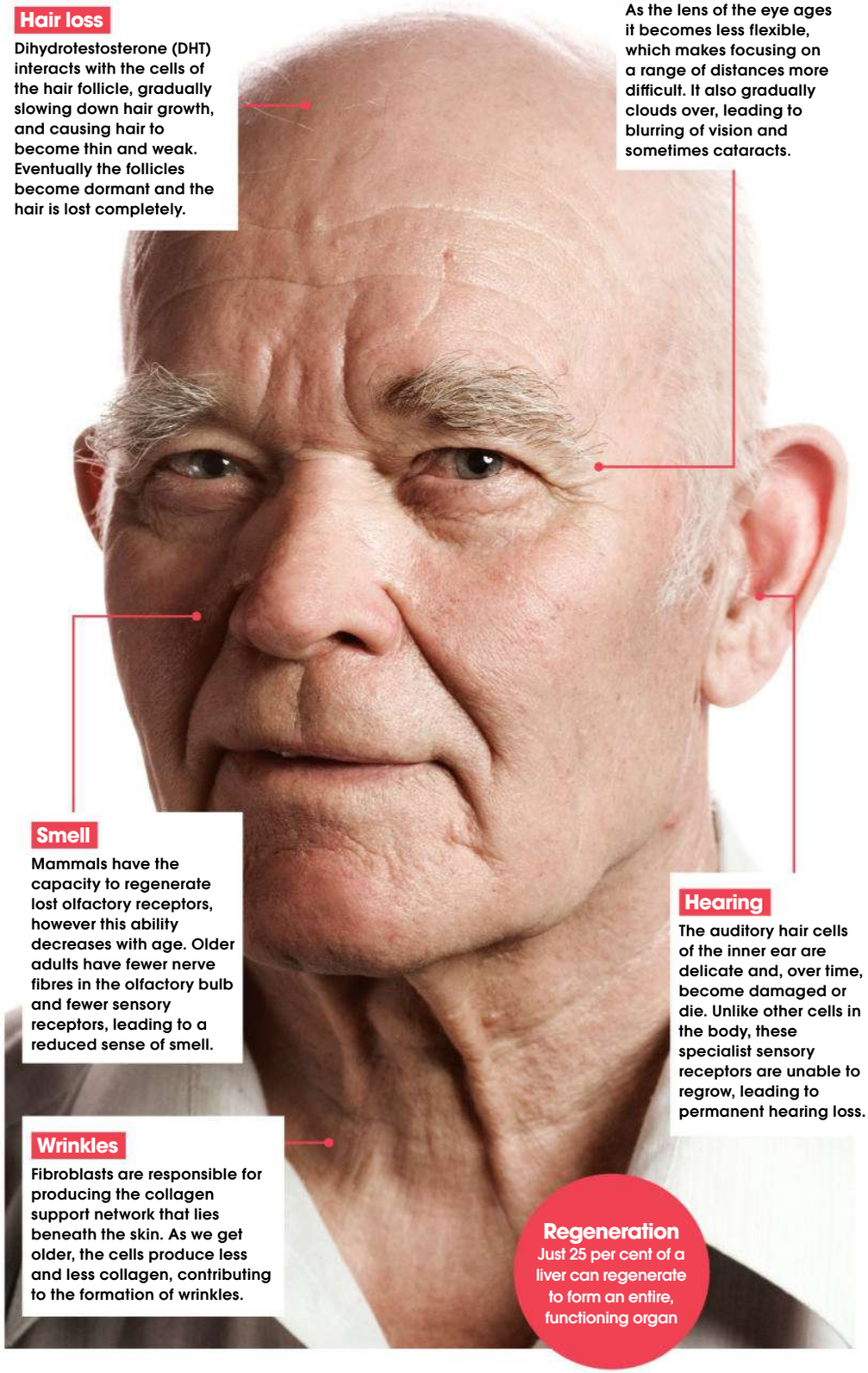
Dramatic changes, such as the menopause, produce obvious effects on the body. Female sex hormones are not just involved in reproduction, but also play a role in other processes, such as the maintenance of bone density. In the absence of oestrogen, bone mineral density decreases, which can lead to osteoporosis. A similar, but less dramatic, effect can be seen in men as testosterone levels begin to drop.

Similar decline in functionality can be observed throughout the human body; collagen in the skin begins to decrease, insulated axons in the brain shorten, and DNA damage accumulates, leading to an ever greater risk of cancer.

However, it's not all bad. Life expectancy is on the increase, and scientists are coming closer to understanding – and being able to slow – the complex processes of human ageing.

As the body gets older it becomes more susceptible to faulty cells that cause cancer

Arthritis is the main cause of disability in over-55s in industrialised countries



Hair loss

Dihydrotestosterone (DHT) interacts with the cells of the hair follicle, gradually slowing down hair growth, and causing hair to become thin and weak. Eventually the follicles become dormant and the hair is lost completely.

Eyesight

As the lens of the eye ages it becomes less flexible, which makes focusing on a range of distances more difficult. It also gradually clouds over, leading to blurring of vision and sometimes cataracts.

Smell

Mammals have the capacity to regenerate lost olfactory receptors, however this ability decreases with age. Older adults have fewer nerve fibres in the olfactory bulb and fewer sensory receptors, leading to a reduced sense of smell.

Hearing

The auditory hair cells of the inner ear are delicate and, over time, become damaged or die. Unlike other cells in the body, these specialist sensory receptors are unable to regrow, leading to permanent hearing loss.

Wrinkles

Fibroblasts are responsible for producing the collagen support network that lies beneath the skin. As we get older, the cells produce less and less collagen, contributing to the formation of wrinkles.

Regeneration

Just 25 per cent of a liver can regenerate to form an entire, functioning organ

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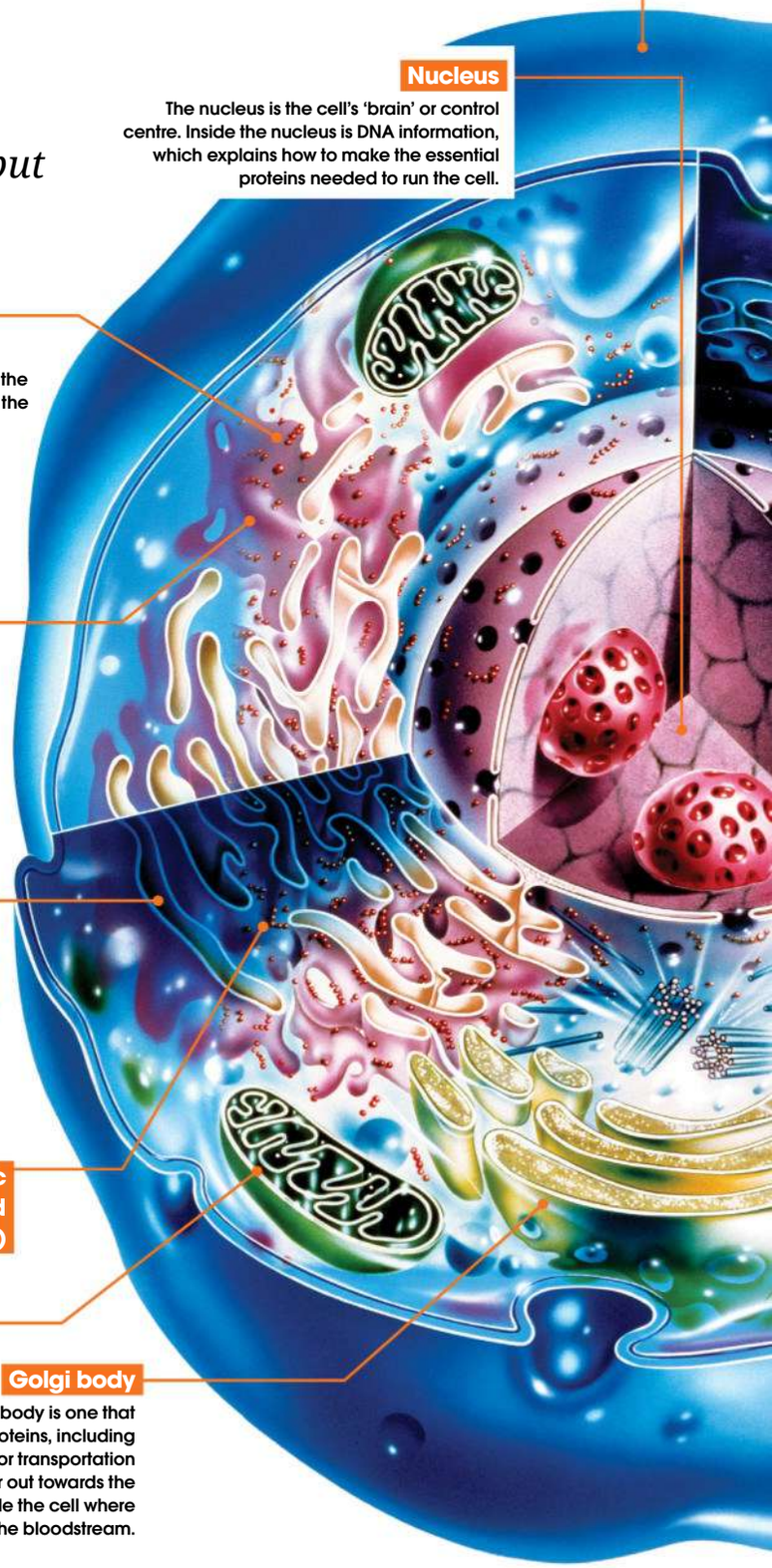
Cell structure explained

The human body has over 75 trillion cells, but what are they and how do they work?

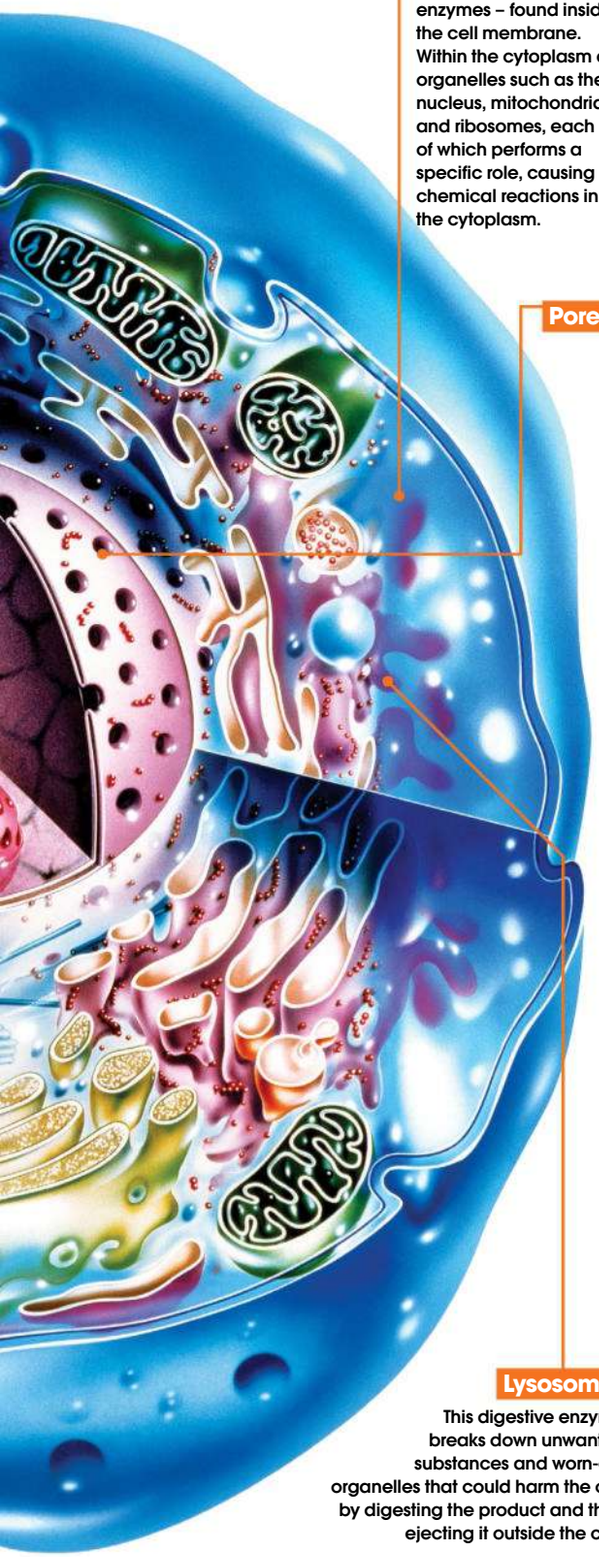
Cells are life and cells are alive. You are here because every cell inside your body has a specific function and a very specialised job to do. There are many different types of cell, each one working to keep the body's various systems operating. A single cell is the smallest unit of living material in the body capable of life. When grouped together in layers or clusters, however, cells with similar jobs to do form tissue, such as skin or muscle. To keep these cells working, there are thousands of chemical reactions going on all the time.

All animal cells contain a nucleus, which acts like a control hub telling the cell what to do and contains the cell's genetic information (DNA). Most of the material within a cell is a watery, jelly-like substance called cytoplasm (cyto means cell), which circulates around the cell and is held in by a thin external membrane, which consists of two layers. Within the cytoplasm is a variety of structures called organelles, which all have different tasks, such as manufacturing proteins – the cell's key chemicals. One vital example of an organelle is a ribosome; these numerous structures can be found either floating around in the cytoplasm or attached to internal membranes. Ribosomes are crucial in the production of proteins from amino acids.

In turn, proteins are essential to building your cells and carrying out the biochemical reactions the body needs in order to grow and develop and also to repair itself and heal.



Cell anatomy



Cytoplasm
This is the jelly-like substance – made of water, amino acids and enzymes – found inside the cell membrane. Within the cytoplasm are organelles such as the nucleus, mitochondria and ribosomes, each of which performs a specific role, causing chemical reactions in the cytoplasm.

Pore

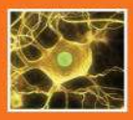
Lysosomes
This digestive enzyme breaks down unwanted substances and worn-out organelles that could harm the cell by digesting the product and then ejecting it outside the cell.

© Science Photo Library

Types of human cell

Around 200 different varieties of cell have been identified, all with specific functions. Discover the main types...

Nerve cells



The cells that make up the nervous system and the brain are nerve cells or neurons. Electrical messages pass between nerve cells along long filaments called axons. To cross the gaps between nerve cells (the synapse) that electrical signal is converted into a chemical signal. These cells enable us to feel sensations, such as pain, and they also enable us to move.

Bone cells

© SPL

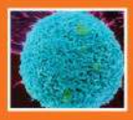
The cells that make up bone matrix – the hard structure that makes bones strong – consist of three main types. Your bone mass is constantly changing and reforming and each of the three bone cells plays its part in this process. First the osteoblasts, which come from bone marrow, build up bone mass and structure. These cells then become buried in the matrix at which point they become known as osteocytes. Osteocytes make up around 90 per cent of the cells in your skeleton and are responsible for maintaining the bone material. Finally, while the osteoblasts add to bone mass, osteoclasts are the cells capable of dissolving bone and changing its mass.

Photoreceptor cells

© SPL

The cones and rods on the retina at the back of the eye are known as photoreceptor cells. These contain light-sensitive pigments that convert the image that enters the eye into nerve signals, which the brain interprets as pictures. The rods enable you to perceive light, dark and movement, while the cones bring colour to your world.

Liver cells



© SPL

The cells in your liver are responsible for regulating the composition of your blood. These cells filter out toxins as well as controlling fat, sugar and amino acid levels. Around 80 per cent of the liver's mass consists of hepatocytes, which are the liver's specialised cells that are involved with the production of proteins and bile.

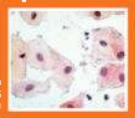
Muscle cells

There are three types of muscle cell – skeletal, cardiac and smooth – and each differs depending on the function it performs and its location in the body. Skeletal muscles contain long fibres that attach to bone. When triggered by a nerve signal, the muscle contracts and pulls the bone with it, making you move. We can control skeletal muscles because they are voluntary. Cardiac muscles, meanwhile, are involuntary, which is fortunate because they are used to keep your heart beating. Found in the walls of the heart, these muscles create their own stimuli to contract without input from the brain. Smooth muscles, which are pretty slow and also involuntary, make up the linings of hollow structures such as blood vessels and your digestive tract. Their wave-like contraction aids the transport of blood around the entire body and the digestion of food.

Fat cells

These cells – also known as adipocytes or lipocytes – make up your adipose tissue, or body fat, which can cushion, insulate and protect the body. This tissue is found beneath your skin and also surrounding your other organs. The size of a fat cell can increase or decrease depending on the amount of energy it stores. If we gain weight the cells fill with more watery fat, and eventually the number of fat cells will begin to increase. There are two types of adipose tissue: white and brown. The white adipose tissue stores energy and insulates the body by maintaining body heat. The brown adipose tissue, on the other hand, can actually create heat and isn't burned for energy – this is why animals are able to hibernate for months on end without food.

Epithelial cells



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Epithelial cells make up the epithelial tissue that lines and protects your organs and constitute the primary material of your skin. These tissues form a barrier between the precious organs and unwanted pathogens or other fluids. As well as covering your skin, you'll find epithelial cells inside your nose, around your lungs and in your mouth.

Red blood cells

Unlike all the other cells in your body, your red blood cells (also known as erythrocytes) do not contain a nucleus. You are topped up with around 25 trillion red blood cells – that's a third of all your cells, making them the most common cell found in your body. Formed in the bone marrow, these cells are important because they carry oxygen to all the different tissues in your body. Oxygen is carried in haemoglobin, a pigmented protein that gives the blood cells their recognisable red colour.

Inside a nucleus

Dissecting the control centre of a cell

Surrounded by cytoplasm, the nucleus contains a cell's DNA and controls all of its functions and processes such as movement and reproduction.

There are two main types of cell: eukaryotic and prokaryotic. Eukaryotic cells contain a nucleus while prokaryotic do not. Some eukaryotic cells have more than one nucleus – called multinucleate cells – occurring when fusion or division creates two or more nuclei.

At the heart of a nucleus you'll find the nucleolus; this particular area is essential in the formation of ribosomes. Ribosomes are responsible for making proteins out of amino acids which take care of growth and repair.

The nucleus is the most protected part of the cell. In animal cells it is located near the centre and away from the membrane for maximum cushioning. As well as the jelly-like cytoplasm around it, the nucleus is filled with nucleoplasm, a viscous liquid which maintains its structural integrity.

Conversely, in plant cells, the nucleus is more sporadically placed due to the fact that plant cells have a larger vacuole and a protective cell wall.

Central command

Take a peek at what's happening inside the 'brain' of a eukaryotic cell

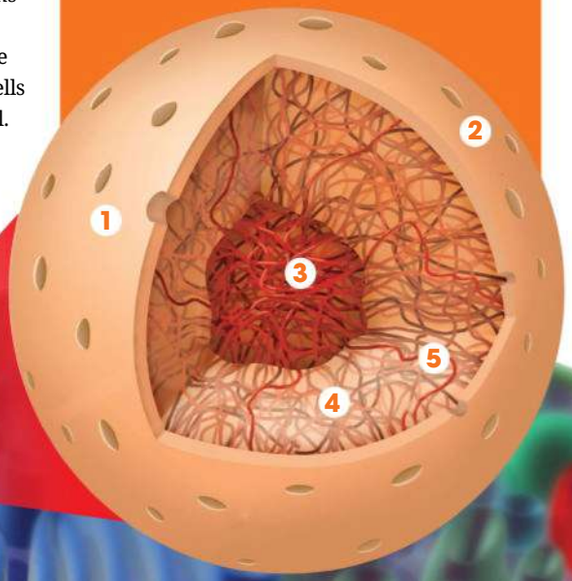
1 Nuclear pore
These channels control the movement of molecules between the nucleus and cytoplasm.

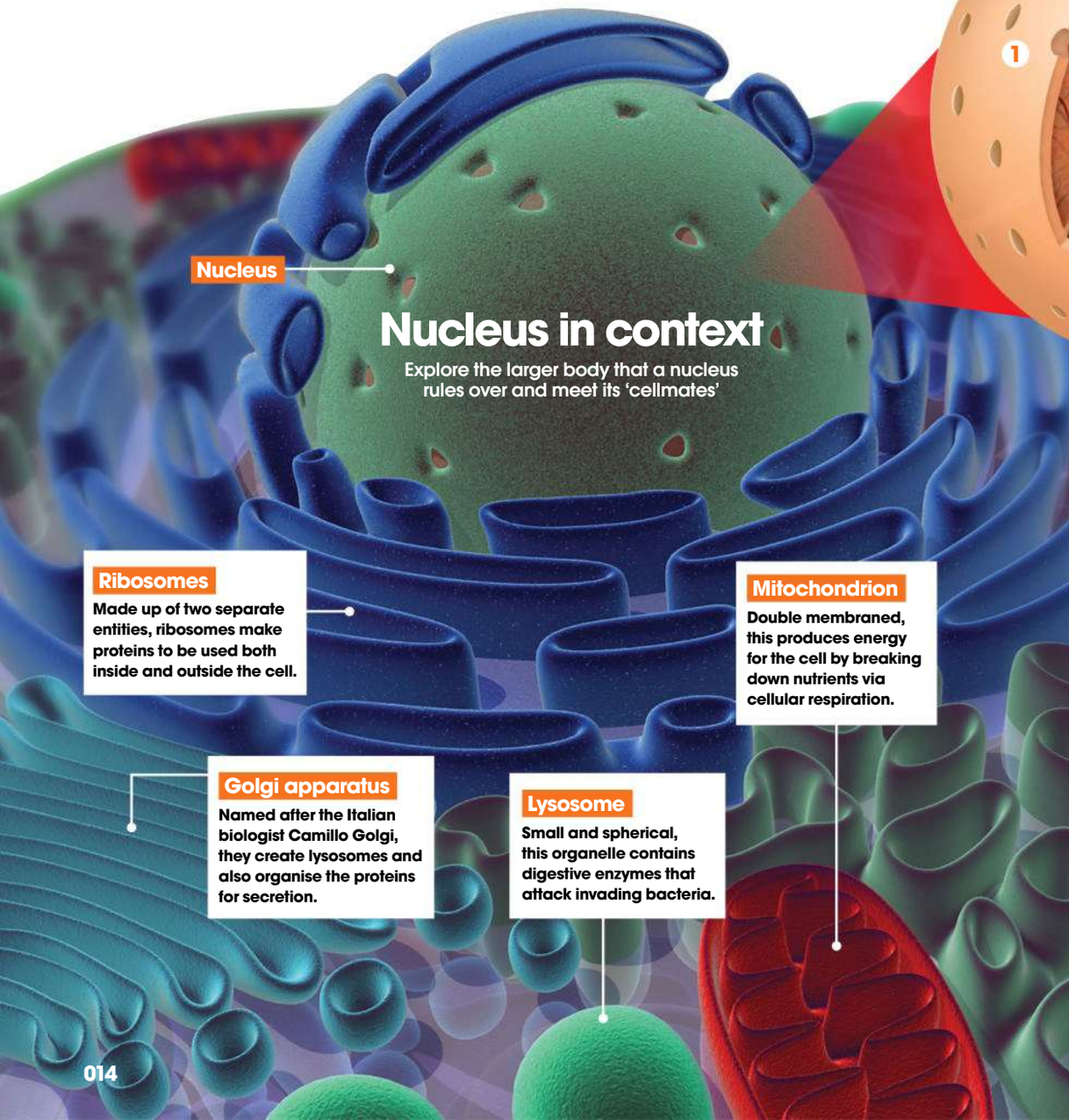
2 Nuclear envelope
Acts as a wall to protect the DNA within the nucleus and regulates cytoplasm access.

3 Nucleolus
Made up of protein and RNA, this is the heart of the nucleus which manufactures ribosomes.

4 Nucleoplasm
This semi-liquid, semi-jelly material surrounds the nucleolus and keeps the organelle's structure.

5 Chromatin
Produces chromosomes and aids cell division by condensing DNA molecules.





Nucleus in context

Explore the larger body that a nucleus rules over and meet its 'cellmates'

How do cells survive without a nucleus?

Prokaryotic cells are actually much more basic than their eukaryotic counterparts. Not only are they up to 100 times smaller but they alsoare mainly a comprising species of bacteria, prokaryotic cells have fewer functions than other cells, so they do not require a nucleus to act as the control centre for the organism.

Instead, these cells have their DNA moving around the cell rather than being housed in a nucleus. They have no chloroplasts, no membrane-bound organelles and they don't undertake cell division in the form of mitosis or meiosis like eukaryotic cells do.

Prokaryotic cells divide asexually with DNA molecules replicating themselves in a process that is known as binary fission.

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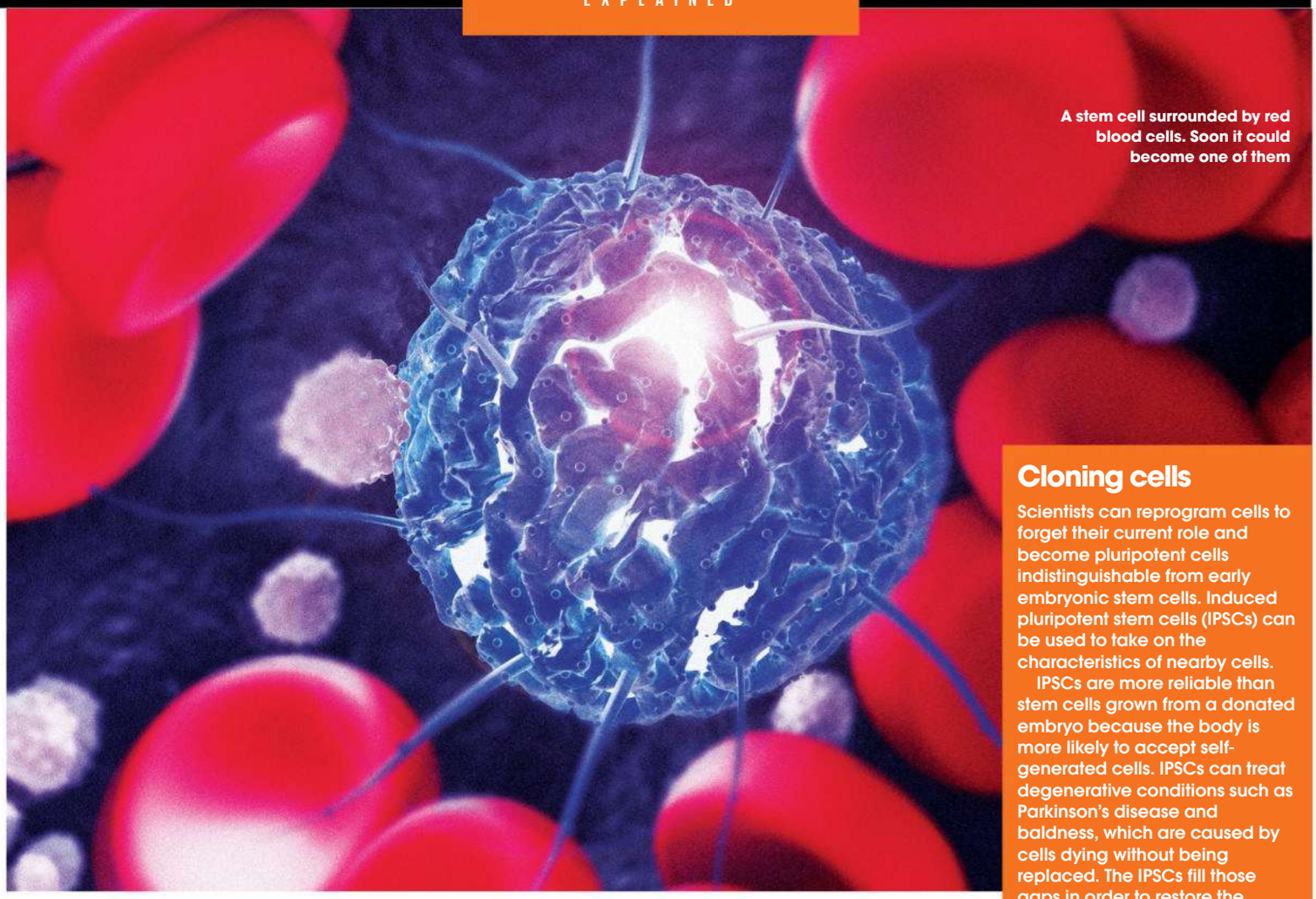


A stem cell surrounded by red blood cells. Soon it could become one of them

What are stem cells?

Understand how these building blocks bring new life

Stem cells are incredibly special because they have the potential to become any kind of cell in the body, from red blood cells to brain cells. They are essential to life and growth, as they repair tissues and replace dead cells. Skin, for example, is constantly replenished by skin stem cells.

Stem cells begin their life cycle as generic, featureless cells that don't contain tissue-specific structures, such as the ability to carry oxygen. Stem cells become specialised through a process called differentiation. This is triggered by signals inside and outside the cell. Internal signals come from strands of DNA that carry information for all cellular structures, while external signals include chemicals from nearby cells. Stem cells can replicate many times – known as proliferation – while others such as nerve cells don't divide at all.

There are two stem cell types, as Professor Paul Fairchild, co-director of the Oxford Stem Cell Institute at Oxford Martin School explains: "Adult stem cells are multipotent, which means they are able to produce numerous cells that are loosely related, such as stem cells in the bone marrow can generate cells that make up the blood," he says. "In contrast, pluripotent stem cells, found within developing embryos, are able to make any one of the estimated 210 cell types that make up the human body."

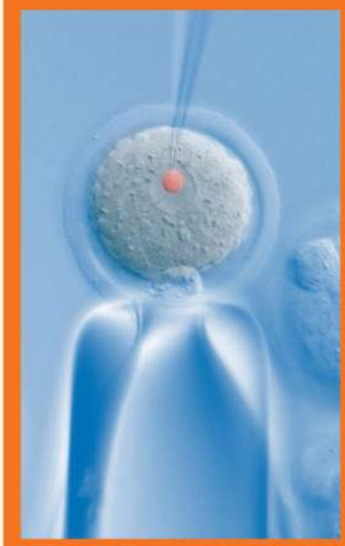
This fascinating ability to transform and divide has made stem cells a rich source for medical research. Once their true potential has been harnessed, they could be used to treat a huge range of diseases and disabilities.

Cloning cells

Scientists can reprogram cells to forget their current role and become pluripotent cells indistinguishable from early embryonic stem cells. Induced pluripotent stem cells (IPSCs) can be used to take on the characteristics of nearby cells.

IPSCs are more reliable than stem cells grown from a donated embryo because the body is more likely to accept self-generated cells. IPSCs can treat degenerative conditions such as Parkinson's disease and baldness, which are caused by cells dying without being replaced. The IPSCs fill those gaps in order to restore the body's systems.

Professor Fairchild explains the process to us: "By deriving these cells from individuals with rare conditions, we are able to model the condition in the laboratory and investigate the effects of new drugs on that disease."



Research on cloning cells can help cure diseases

Your skeleton

This incredible living framework provides more than just structural support

80% compact bone
20% spongy bone

The human skeleton is crucial for us to live. Our bones make up a strong, flexible framework that protects our vital organs, keeps our shape and allows our bodies to move, as well as being a stem-cell reserve. Bones also produce blood cells within bone marrow and store minerals we need released on a daily basis.

As an adult you will have around 206 bones, but you are born with over 270, which continue to grow, strengthen and fuse after birth until around 18 in females and 20 in males. Skeletons actually do vary between sexes in structure also. One of the most obvious areas is the pelvis as a female must be able to give birth, and therefore hips are comparatively shallower and wider. The cranium also becomes more robust in males due to heavy muscle attachment and a male's chin is often more prominent. Female skeletons are generally more delicate overall. However, although there are several methods, sexing can be difficult because of the level of variation we see within the species.

206 bones in the adult human body

Bone is a composite material, constructed from three basic ingredients: collagen strands, a sugary protein glue and inorganic calcium salts. The collagen fibres are arranged in alternating layers, crossing over one another, providing a flexible scaffold, and calcium salts are glued in between for strength and rigidity. In utero, the skeleton takes shape as cartilage, which then starts to calcify and develop during gestation and following birth. The primary element that makes up bone, osseous tissue, is actually mineralised calcium phosphate, but other forms of tissue such as marrow, cartilage and blood vessels are also contained in the overall structure. Many individuals think that bones are solid, but actually inner bone is porous and full of little holes.

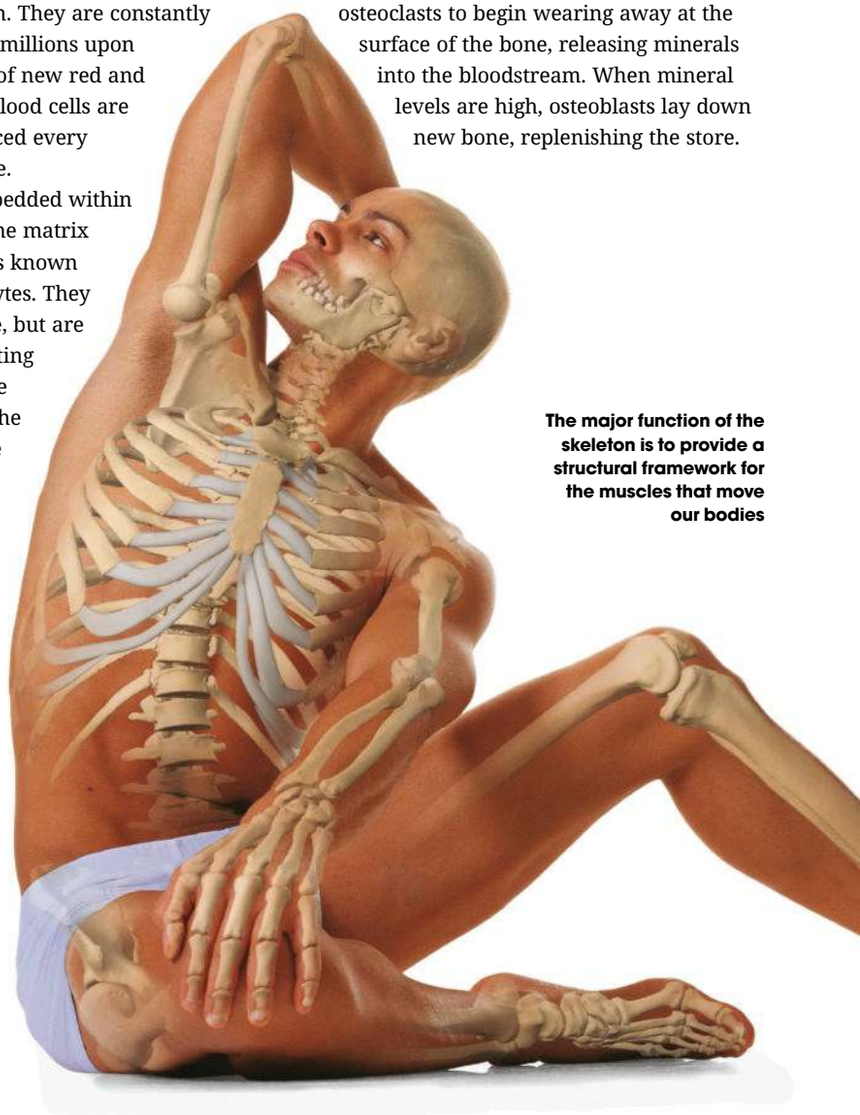
The outside of each bone is composed of plates, or hollow tubes, of dense cortical bone, supported on the inside by a honeycomb network of spongy trabecular bone. This network is slightly flexible and helps to distribute the load, curving the tensile and compressive forces across the ends of the bone, while providing maximum strength.

Spongy bone is also home to the bone marrow, which houses stem cells capable of producing most of the cells of the blood and immune system. They are constantly active, and millions upon millions of new red and white blood cells are produced every minute.

Embedded within the bone matrix are cells known as osteocytes. They do not move, but are capable of detecting stresses inside the bone itself, and can trigger the formation of new bone in a process known as remodelling. The old bone is broken down by large cells known as osteoclasts, and new collagen and minerals are deposited by smaller osteoblasts.

Even though cells are constantly being replaced, and therefore no cell in our body is more than 20 years old, they are not replaced with perfect, brand-new cells. The cells contain errors in their DNA and ultimately our bones therefore weaken as we age. Conditions such as arthritis and osteoporosis can often be caused by ageing and cause issues with weakening of bones and reduced movement ability.

Together, the two cell types are able to release and store calcium and phosphorous in the skeleton for use elsewhere in the body. They are under the influence of hormones released by glands in the brain, and when levels of minerals run low in the body, the signals encourage the osteoclasts to begin wearing away at the surface of the bone, releasing minerals into the bloodstream. When mineral levels are high, osteoblasts lay down new bone, replenishing the store.



The major function of the skeleton is to provide a structural framework for the muscles that move our bodies

Bone structure

The long bones are formed into tubes, closed at both ends and capped with cartilage

Epiphysis
The ends of the long bones act as shock absorbers, with a casing of tough compact bone supported by a spongy core.

Articular cartilage
The end surfaces of the bones are covered in thick, slippery cartilage, preventing wear at the joints.

Cells known as osteoclasts constantly remodel the surface of bone

Red bone marrow
Blood cells are produced in red bone marrow, found between the gaps in the honeycomb structure of the spongy bone at either end.

Compact bone
The outside of the bone is arranged in an orderly, layered structure, providing strength and rigidity.

Blood vessels
Blood vessels travel into and out of the bone through canals in the compact surface.

Spongy bone
This disorganised honeycomb structure is more flexible than compact bone, and its large surface area supports blood-cell production and calcium exchange.

Periosteum
The outside of the bone is covered in a layer of connective tissue, containing cells involved in growth and repair.

Diaphysis
The shafts of the long bones are constructed from densely packed compact bone.

Medullary cavity
The centre of the long bones is filled with yellow bone marrow, containing mainly fat cells.

Endosteum
The inner surface of the bone is lined by a single layer of cells.

Spongy bone has a characteristic honeycomb structure

How bones grow

Newborn
In the womb, most of the skeleton is made of cartilage, but gradually minerals are laid down and it is converted to bone in a process known as ossification.

Growth plate

Marrow cavity

Child
Cartilage continues to form at the growth plates, and calcium salts are added at the secondary ossification centre, lengthening the bone at both ends.

Secondary ossification centre

Blood supply

Adult
The growth plate itself is turned to bone, and stops producing cartilage, preventing the bones from lengthening any further.

Ossified growth plate

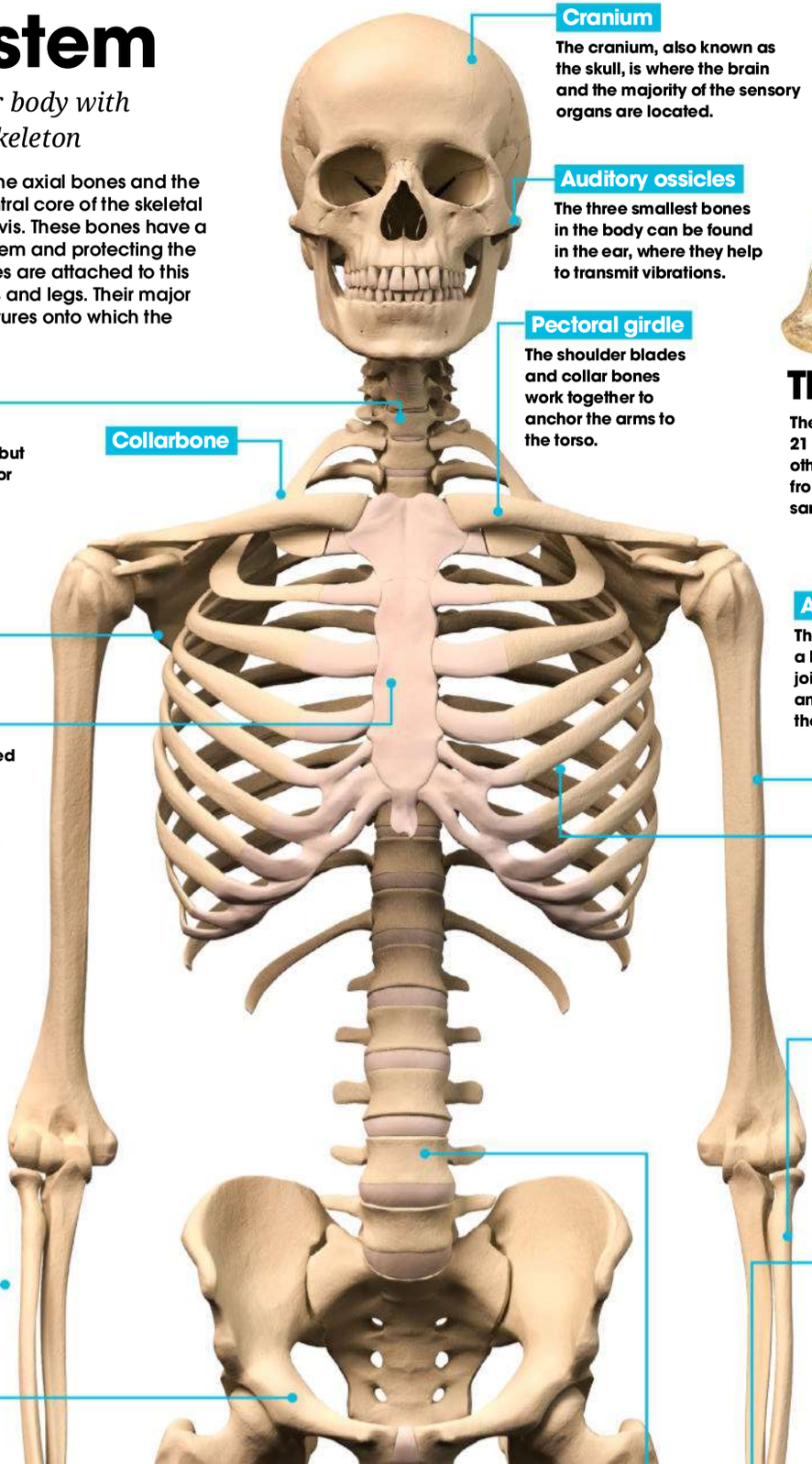
Bone marrow cells

There are two types of bone marrow in the human body; yellow marrow is found in the shafts of the long bones, like the femur, and red marrow is mainly found in the flat bones, like the ribs. Yellow marrow is mostly made up of large fat cells, whilst red marrow contains stem cells. These are capable of producing most of the cells of the blood and immune system, and concealed within the bones are many immature cells in the process of development.

Skeletal system

Get to know the bones in your body with our guide to the human skeleton

There are two major parts to the human skeleton: the axial bones and the appendicular bones. The axial bones form the central core of the skeletal system, including the skull, spine, rib cage and pelvis. These bones have a protective role, supporting the central nervous system and protecting the vital organs from damage. The appendicular bones are attached to this central support, and include the bones of the arms and legs. Their major function is movement, providing rigid jointed structures onto which the muscles are attached.



Cranium
The cranium, also known as the skull, is where the brain and the majority of the sensory organs are located.

Auditory ossicles
The three smallest bones in the body can be found in the ear, where they help to transmit vibrations.

Pectoral girdle
The shoulder blades and collar bones work together to anchor the arms to the torso.

Hyoid
This horseshoe-shaped bone is not attached to the rest of the skeleton, but it helps to provide an anchor point for the tongue, enabling us to speak.

Collarbone

Scapula

Sternum
The ribs are anchored to the sternum by cartilage, providing a flexible linkage and allowing the rib cage to contract and expand.

Radius/Ulna
The radius and ulna are the bones situated in the forearm. They connect the wrist and the elbow.

Pelvis
This is the transitional joint between the trunk of the body and the legs. It is one of the key areas in which we can see the skeletal differences between the sexes.

Females have a larger opening inside the pelvis, aiding childbirth

The male pelvis is relatively narrow and the opening is heart-shaped

The skull

The skull is constructed out of 22 plates of flat bone, 21 of which are permanently fused together. The other is the mandible, or jawbone. They are made from a thick layer of organised cortical bone, sandwiched around a centre of spongy bone.

Arm
The humerus makes a ball-and-socket joint at the shoulder, and a hinge joint at the elbow.

10 years to replace your entire skeleton

Ribs
Most people have 12 pairs of ribs that form a protective cage for organs situated in the chest cavity. They join to the vertebrae in the spine at the back of the body, and the sternum at the front.

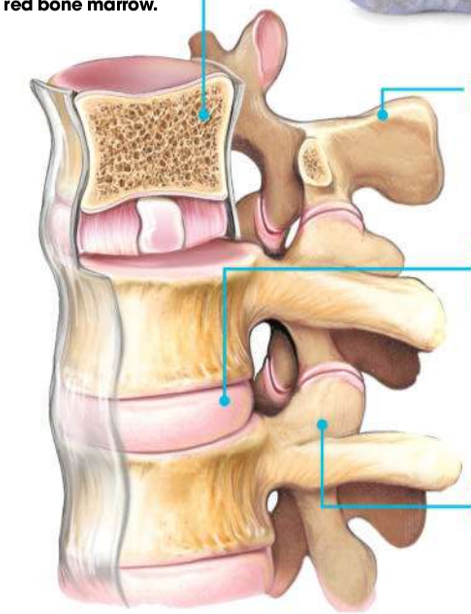
Forearm
The radius and ulna are the bones situated in the forearm. They connect the wrist and the elbow. The two bones split the load; the ulna bears weight near the elbow, and the radius bears weight near the wrist.

Metacarpals
The long bones in the hands are called metacarpals, and are the equivalent of metatarsals in the foot. Phalanges located close to the metacarpals make up the fingers.

The spine

There are 33 vertebrae in the spinal column, divided into categories according to their shape and location. There are seven cervical in the neck, 12 thoracic vertebrae in the chest, each of which attaches to a pair of ribs, and five load-bearing lumbar vertebrae in the lower back. The remainder of the vertebrae are fused to form the sacrum and coccyx.

33 vertebrae in the spine

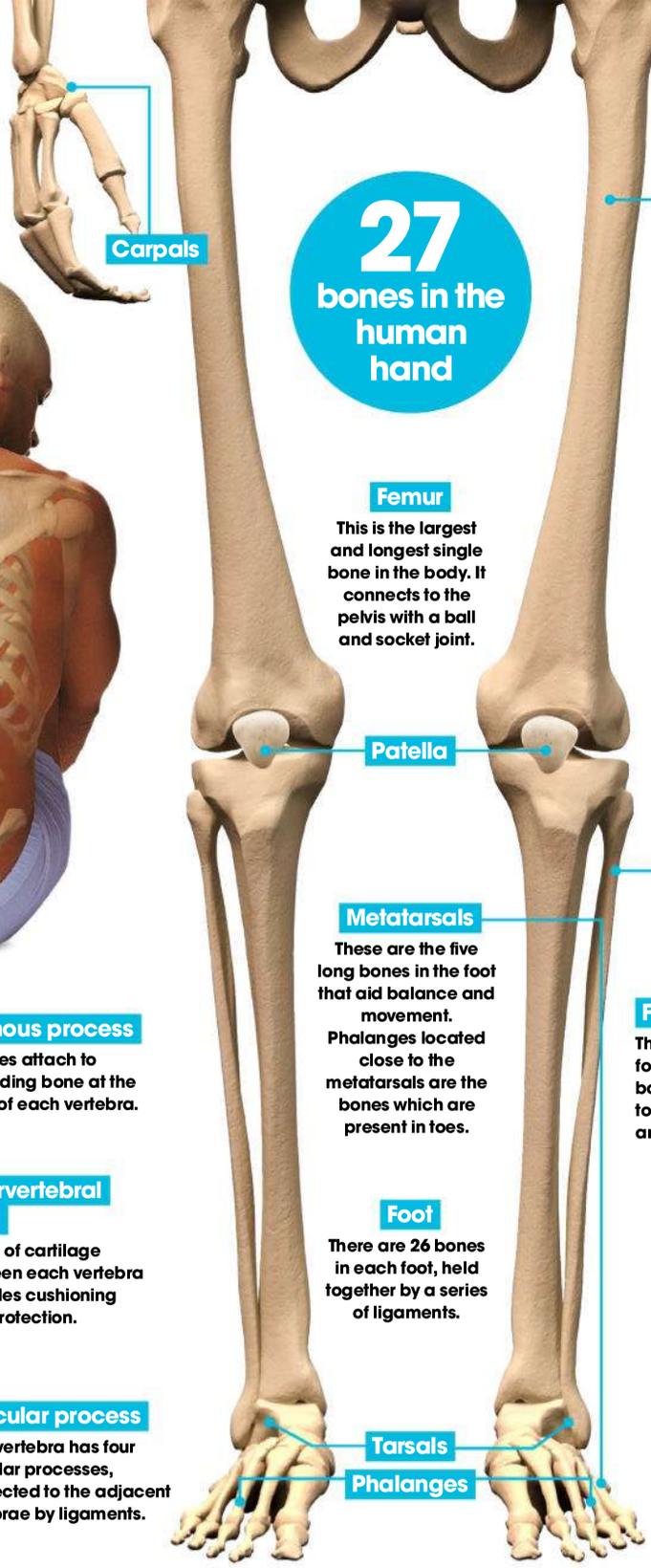


Vertebral body
Each vertebra contains a core of spongy bone and red bone marrow.

Spinous process
Muscles attach to protruding bone at the back of each vertebra.

Intervertebral disk
A disk of cartilage between each vertebra provides cushioning and protection.

Articular process
Each vertebra has four articular processes, connected to the adjacent vertebrae by ligaments.



27 bones in the human hand

Carpals

Femur
This is the largest and longest single bone in the body. It connects to the pelvis with a ball and socket joint.

Patella

Metatarsals
These are the five long bones in the foot that aid balance and movement. Phalanges located close to the metatarsals are the bones which are present in toes.

Foot
There are 26 bones in each foot, held together by a series of ligaments.

Tarsals

Phalanges

Wrist, hand and fingers
There are 27 bones in each hand, eight of which make up the wrist.

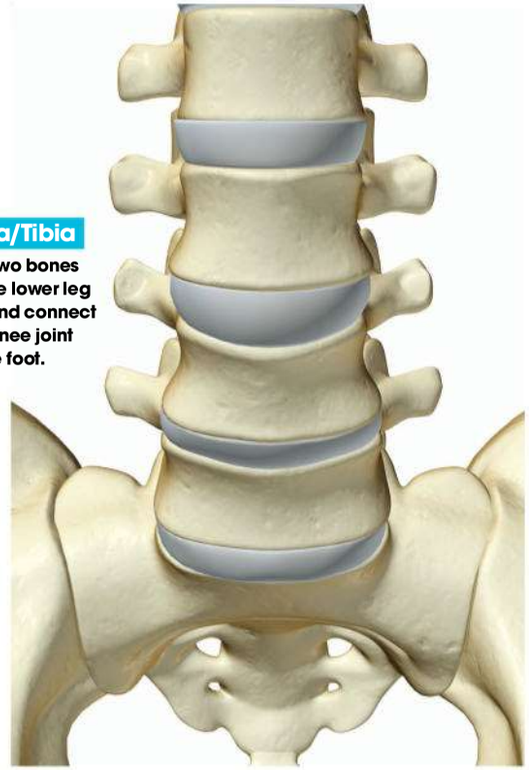
Lower limb
The weight of the body is supported by the femur (thigh bone) and the tibia (shin bone), while the fibula is involved in anchoring the muscles of the foot.

Vertebrae
There are three main kinds of vertebrae (excluding the sacrum and coccyx) – cervical, thoracic and lumbar. These vary in strength and structure as they carry different pressure within the spine.

Fibula/Tibia
These two bones form the lower leg bone and connect to the knee joint and the foot.

Shock absorbers

Between the vertebrae of the spine are disks of a springy tissue known as fibrocartilage, made up of long chains of collagen and bound together by a gel of sugary proteins, known as glycoproteins. These have a strong affinity for water, so as a result, the entire tissue is filled with fluid. It acts like suspension, compressing and deforming under load and protecting the bones from the stress of day-to-day impact.



Joints

For individual bones to function together, they must be linked by joints

Some bones, like those in the skull, don't need to move and are permanently fused together with mineral sutures. These are known as fixed joints and provide maximum stability.

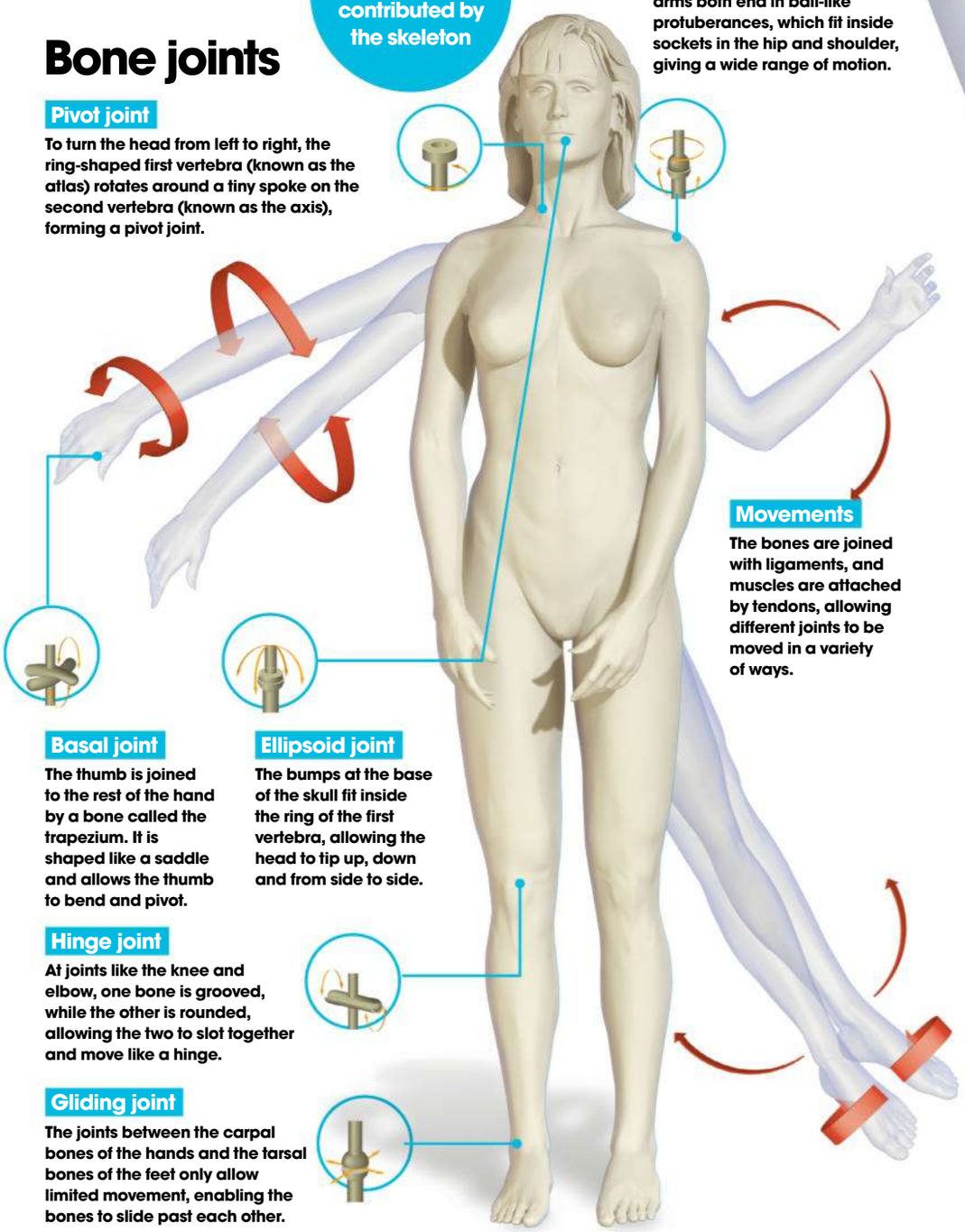
However, most bones need flexible linkages. In some parts of the skeleton, partial flexibility is sufficient, so all that the bones require is a little cushioning to prevent rubbing. The bones are joined by a rigid gel-like tissue known as cartilage, which allows for a small range of compression and stretching. These types of joints are used where the ribs meet the sternum, for flexibility when breathing, and between the vertebrae of the spinal column, so it can bend and flex without crushing the spinal cord.

Most joints require a larger range of movement. Covering the ends of the bones in cartilage provides shock absorption, but for them to move freely in a socket, the cartilage must be lubricated to make it slippery and wear-proof. At synovial joints, the ends of the two bones are encased in a capsule, covered on the inside by a synovial membrane, which fills the joint with synovial fluid, allowing the bones to slide smoothly past one another.

There are different types of synovial joint, with varying ranges of motion. Ball-and-socket joints are used at the shoulder and hip, and provide a wide range of motion, allowing the curved surface at the top end of each limb to slide inside a cartilage covered cup. The knees and elbows have hinge joints, which interlock in one plane, allowing the joint to open and close. For areas that need to be flexible, but do not need to move freely, such as the feet, gliding joints allow the bones to slide small distances without rubbing.

Bone joints

15% body weight contributed by the skeleton



Pivot joint

To turn the head from left to right, the ring-shaped first vertebra (known as the atlas) rotates around a tiny spoke on the second vertebra (known as the axis), forming a pivot joint.

Ball-and-socket joint

The long bones of the legs and arms both end in ball-like protuberances, which fit inside sockets in the hip and shoulder, giving a wide range of motion.

Movements

The bones are joined with ligaments, and muscles are attached by tendons, allowing different joints to be moved in a variety of ways.

Basal joint

The thumb is joined to the rest of the hand by a bone called the trapezium. It is shaped like a saddle and allows the thumb to bend and pivot.

Ellipsoid joint

The bumps at the base of the skull fit inside the ring of the first vertebra, allowing the head to tip up, down and from side to side.

Hinge joint

At joints like the knee and elbow, one bone is grooved, while the other is rounded, allowing the two to slot together and move like a hinge.

Gliding joint

The joints between the carpal bones of the hands and the tarsal bones of the feet only allow limited movement, enabling the bones to slide past each other.

Hypermobility

Some people have particularly flexible joints, so have a much larger range of motion than others. This is sometimes known as being 'double jointed.' It is thought to result from a combination of factors, including the structure of the collagen in the joints, the shape of the end of the bones, and the tone of the muscles around the joint.

Mobile

The synovial joints are the most mobile in the human body. The ends of the bones are linked by a capsule, which contains a fluid lubricant, allowing the bones to slide past one another as they move. Synovial joints come in different types, including ball-and-socket, hinge, and gliding, and they are the most common type of joint in the body.

Semimobile

Cartilaginous joints do not allow free motion, but provide cushioning for smaller movements. Instead of a lubricated capsule, the bones are joined by fibrous or hyaline cartilage. The linkage provides less flexibility than a synovial joint, but acts as a shock absorber, so the bones can move apart and together over small distances.

Fixed

Some bones do not need to move relative to one another, so instead of a flexible joint, they are permanently fused. The best example is the cranium, which starts out as separate pieces, allowing the foetal head to change shape to fit through the birth canal, and fuses after birth to encase the brain in a solid protective skull.

Why our joints crack

The synovial fluid used to lubricate the joints contains dissolved gasses. The fluid is sealed within a capsule, so if the joint is stretched, the capsule also stretches, creating a vacuum as the pressure changes, and pulling the gas out of solution and into a bubble, which pops, producing a cracking sound.

Muscle
The quadriceps muscle group runs down the front of the femur and finishes in a tendon attached to the knee cap.

Artery
The femoral artery supplies blood to the lower leg, and its branches travel around the knee joint and over the patella.

Synovial membrane
The membrane surrounding the interior of the joint produces a lubricant called synovial fluid.

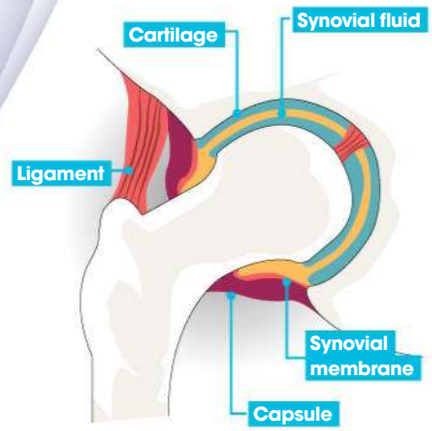
Knee cap
The patella prevents the tendons at the front of the leg from wearing away at the joint.

300+ bones in a newborn baby

External ligaments
The joint is held together by four ligaments that connect the femur to the bones of the lower leg.

Patellar ligament
The patellar ligament connects the kneecap to both the quadriceps in the thigh and the tibia in the lower leg.

Meniscus
Each of the bones is capped with a protective layer of cartilage, preventing friction and wear.



9kg weight of average human skeleton

Fibula
The end of the fibula (calf bone) has two rounded bumps, separated by a deep groove.

Tibia
The rounded ends of the fibula fit in to two concave slots at the top of the tibia (shin bone).

Inside a joint

Synovial joints prevent mobile areas of the skeleton from grinding against one another as they move. The two bones are loosely connected by strips of connective tissue called tendons, and the two ends are encased in a capsule, which is lined by a synovial membrane. The bones are covered in smooth cartilage to prevent abrasion and the membrane produces a nourishing lubricant to ensure the joint moves smoothly.

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How our muscles work

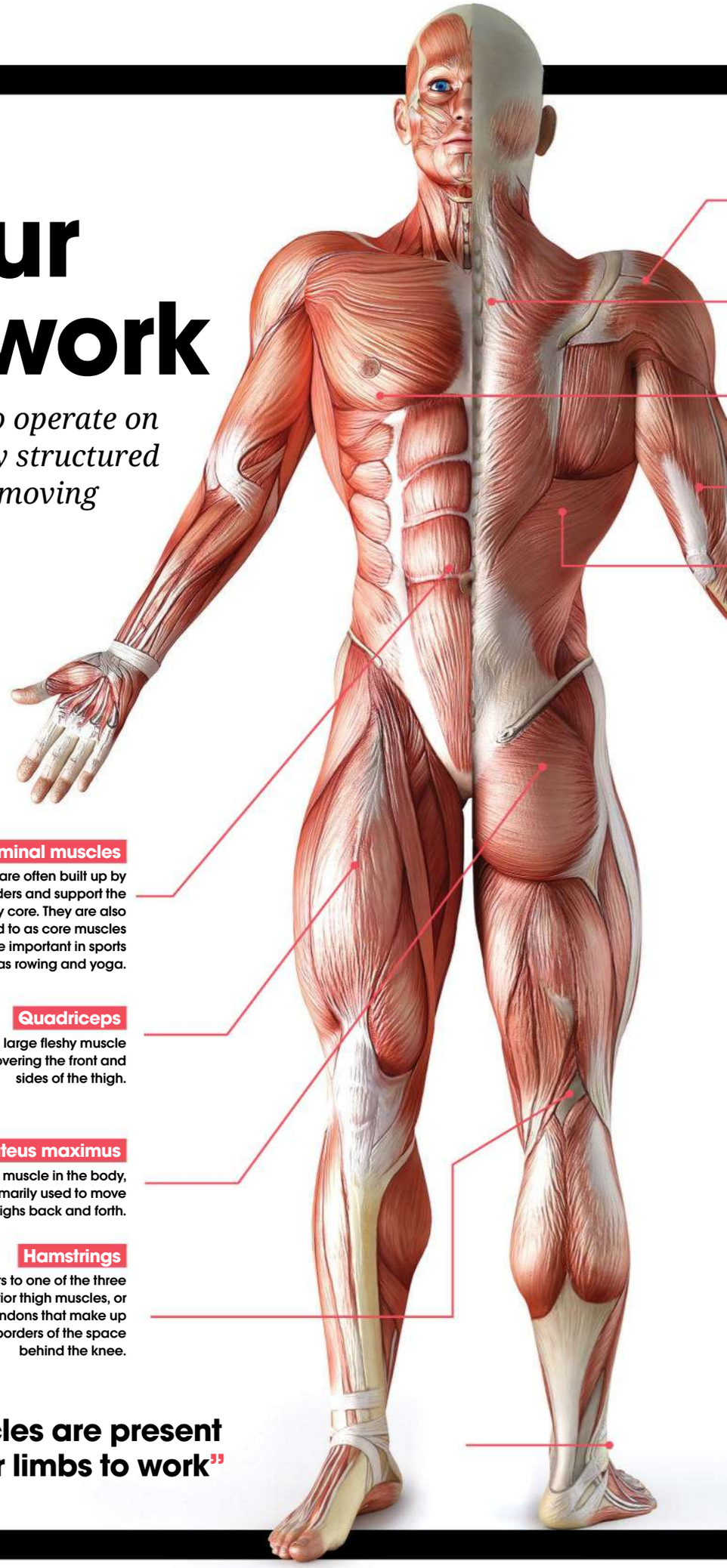
Muscles are essential for us to operate on a daily basis, but how are they structured and how do they keep us moving

A muscle is a group of tissue fibres that contract and release to control movements within the body. We have three different types of muscles in our bodies – smooth muscle, cardiac muscle and skeletal muscle.

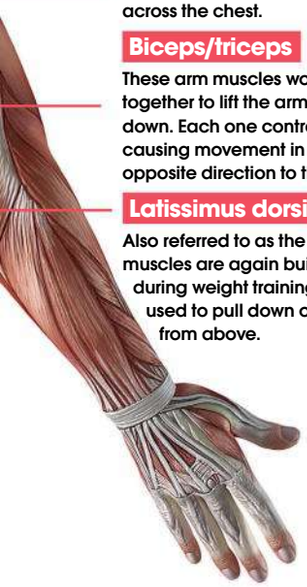
Skeletal muscle, also known as striated muscle, is what we would commonly perceive as muscle, this being external muscles that are attached to the skeleton, such as biceps and deltoids. These muscles are connected to the skeleton with tendons. Cardiac muscle concerns the heart, which is crucial as it pumps blood around the body, supplying oxygen and ultimately energy to muscles, which allows them to operate. Smooth muscle, which is normally sheet muscle, is primarily involved in muscle contractions such as bladder control and oesophagus movements. These are often referred to as involuntary as we have little or no control over these muscles' actions.

Muscles control most functions within our bodies; release of waste products, breathing, seeing, eating and movement to name but a few. Actual muscle structure is quite complex, and each muscle is made up of numerous fibres which work together to give the muscle strength. Muscles increase in effectiveness and strength through exercise and growth and the main way this occurs is through small damage caused by each repetition of a muscle movement, which the body then automatically repairs and improves.

More than 640 muscles are actually present across your entire body working to enable your limbs to work, control bodily functions and shape the body as a whole.



"More than 300 individual muscles are present across your body to enable your limbs to work"



Deltoids
These muscles stretch across the shoulders and aid lifting.

Trapezius
Large, superficial muscle at the back of the neck and the upper part of the thorax, or chest.

Pectoralis major
Commonly known as the 'pecs', this group of muscles stretch across the chest.

Biceps/triceps
These arm muscles work together to lift the arm up and down. Each one contracts, causing movement in the opposite direction to the other.

Latissimus dorsi
Also referred to as the 'lats', these muscles are again built up during weight training and are used to pull down objects from above.

What affects our muscle strength?

How strong we are is a combination of nature and nurture

Muscle strength refers to the amount of force that a muscle can produce, while operating at maximum capacity, in one contraction. Size and structure of the muscle is important for muscle strength, with strength being measured in several ways. Consequently, it is hard to definitively state which muscle is actually strongest.

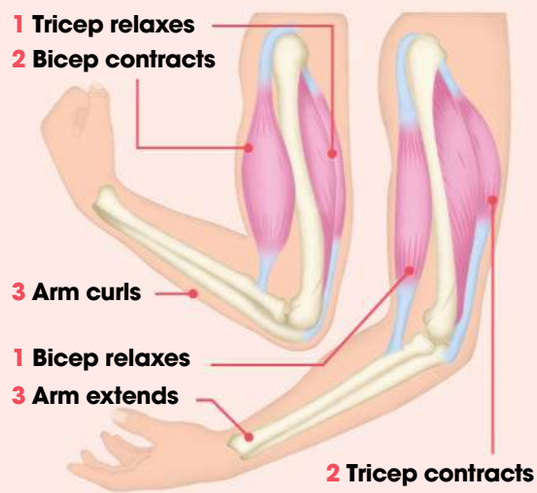
We have two types of muscle fibre: one that supports long, constant usage exerting low levels of pressure, and one that supports brief, high levels of force. The latter is used during anaerobic activity and these fibres respond better to muscle building.

Genetics can affect muscle strength, as can usage, diet and exercise regimes. Contractions of muscles cause injuries in the muscle fibres and it's the healing of these that actually create muscle strength as the injuries are repaired and overall strengthen the muscle.

"Tendons attach muscles such as biceps to bones, allowing muscles to move elements of our body"

How does the arm flex?

Biceps and triceps are a pair of muscles that work together to move the arm up and down. As the bicep contracts, the triceps will relax and stretch out and consequently the arm will move upwards. When the arm needs to move down, the opposite will occur – with the triceps contracting and the bicep relaxing and being forcibly stretched out by the triceps. The bicep is so named a flexor as it bends a joint, and triceps would be the extensor as it straightens the joint out. Neither of these muscles can push themselves straight, they depend on the other to oppose their movements and stretch them out. Many muscles therefore work in pairs, so-called antagonistic muscles.



What are muscles made up of?

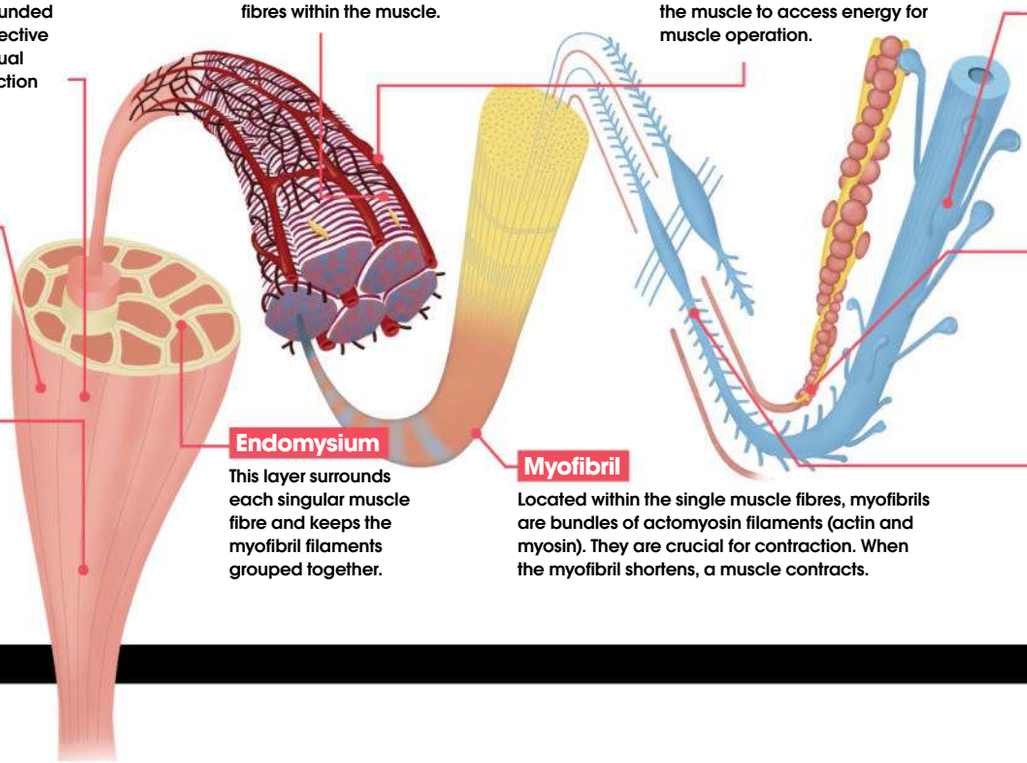
Muscles are made up of numerous cylindrical fibres, which work together to contract and control parts of the body. Muscle fibres are bound together by the perimysium into small bundles, which are then grouped together by the epimysium to form the actual muscle. Blood vessels and nerves also run through the connective tissue to give energy to the muscle and allow feedback to be sent to the brain. Tendons attach muscles such as biceps and triceps to bones, allowing muscles to move elements of our body as we wish.

Fascicle
A bundle of muscle fibres is known as a fascicle. Surrounded by perimysium – the connective tissues that groups individual fibres together – this collection makes up a muscle.

Perimysium
This layer groups together muscle fibres within the muscle.

Blood vessel
This provides oxygen and allows the muscle to access energy for muscle operation.

Myosin
Myosin is also an important protein strand and reacts first when a muscle contracts, subsequently activating the actin thread.



Epimysium
The external layer that covers the muscle overall and keeps the bundles of muscle fibres together.

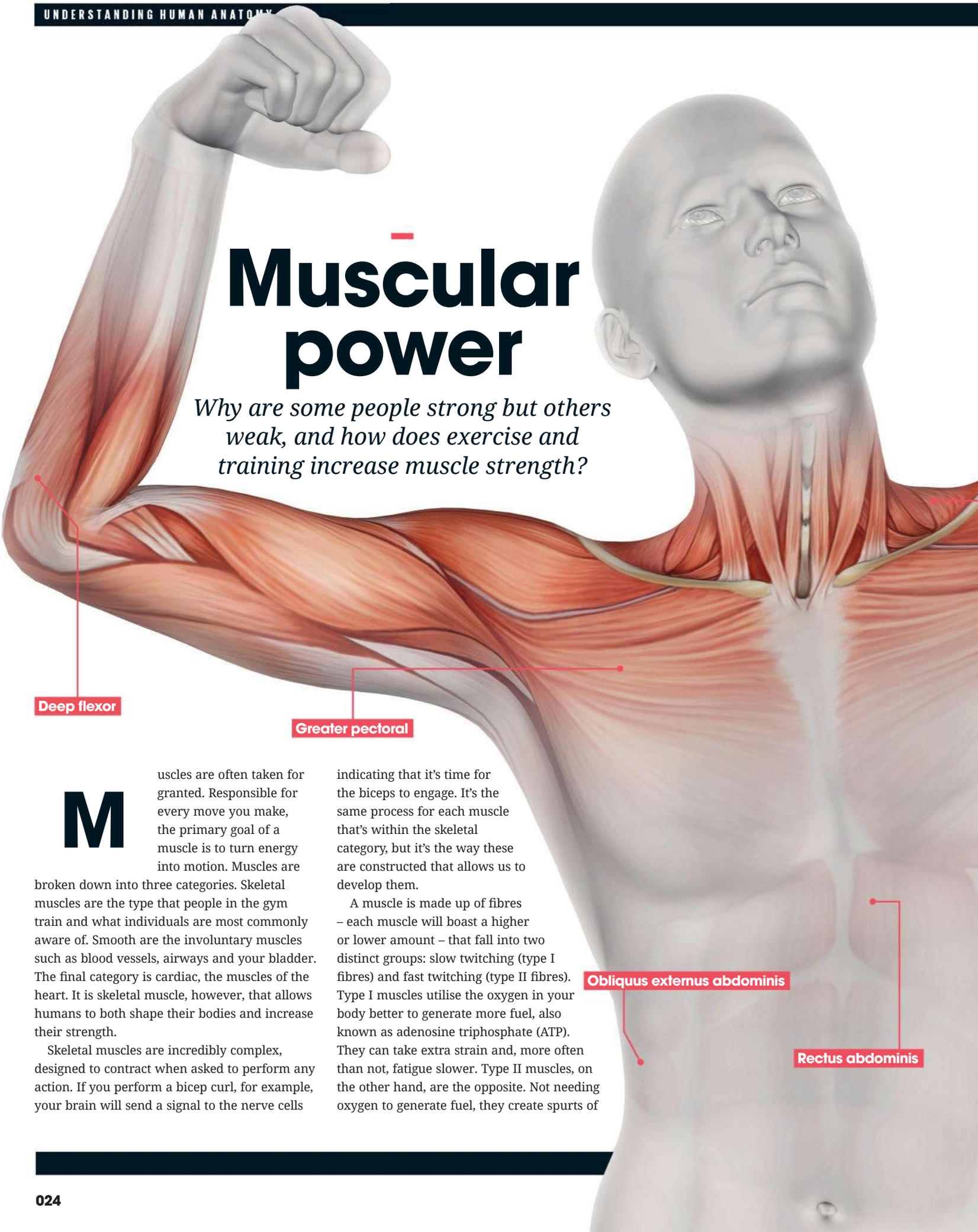
Actin
Found in muscle tissue, actin is a strand of protein. When this and myosin interlock with each other and pull, it activates the shortening of the myofibril .

Tendon
These attach muscle to bones, which in turn enables the muscles to move parts of the body around (off image).

Endomysium
This layer surrounds each singular muscle fibre and keeps the myofibril filaments grouped together.

Myofibril
Located within the single muscle fibres, myofibrils are bundles of actomyosin filaments (actin and myosin). They are crucial for contraction. When the myofibril shortens, a muscle contracts.

Filaments
Myofibrils are constructed of filaments, which are made up of the proteins actin and myosin.



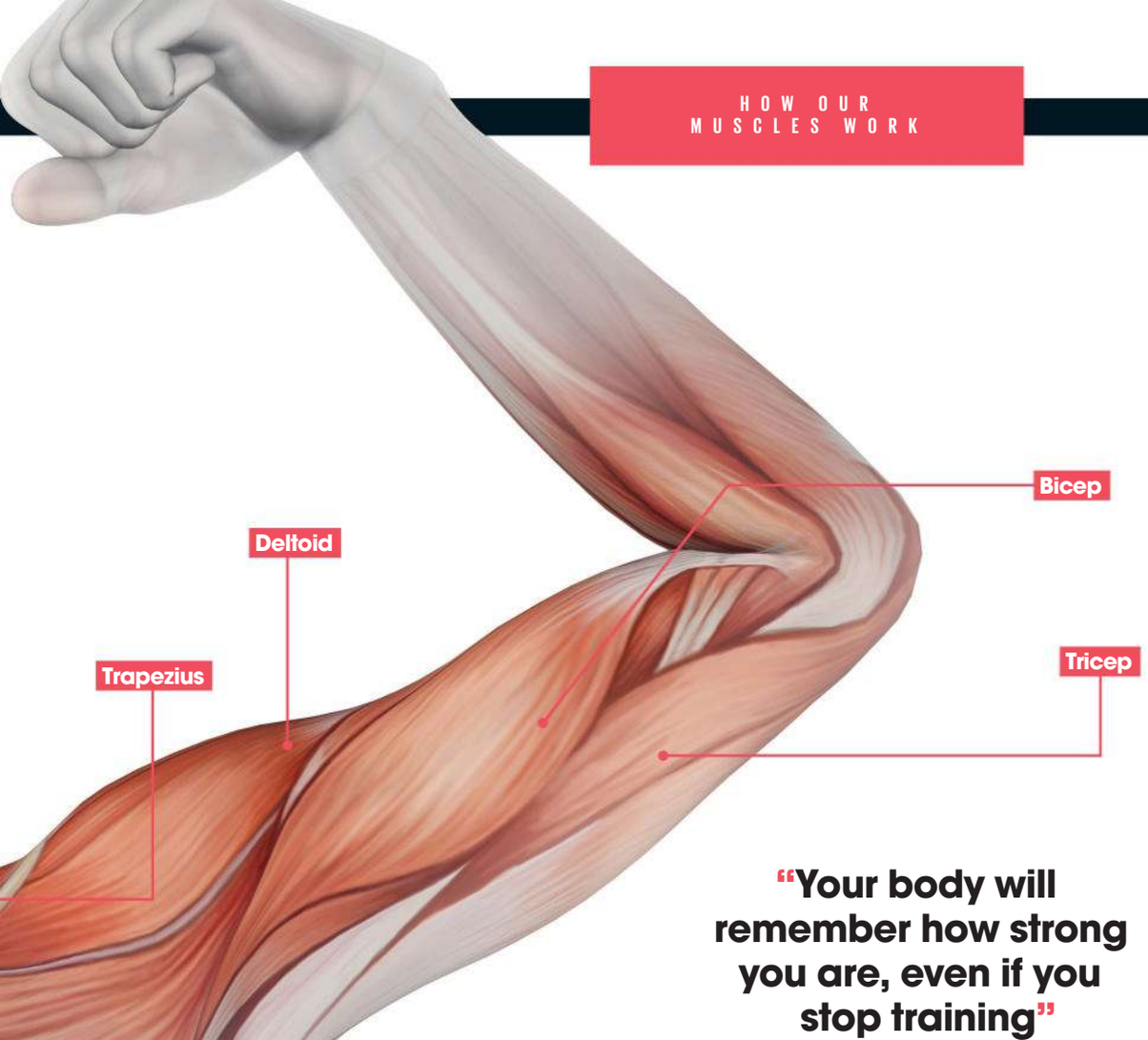
Muscular power

Why are some people strong but others weak, and how does exercise and training increase muscle strength?

Muscles are often taken for granted. Responsible for every move you make, the primary goal of a muscle is to turn energy into motion. Muscles are broken down into three categories. Skeletal muscles are the type that people in the gym train and what individuals are most commonly aware of. Smooth are the involuntary muscles such as blood vessels, airways and your bladder. The final category is cardiac, the muscles of the heart. It is skeletal muscle, however, that allows humans to both shape their bodies and increase their strength.

Skeletal muscles are incredibly complex, designed to contract when asked to perform any action. If you perform a bicep curl, for example, your brain will send a signal to the nerve cells indicating that it's time for the biceps to engage. It's the same process for each muscle that's within the skeletal category, but it's the way these are constructed that allows us to develop them.

A muscle is made up of fibres – each muscle will boast a higher or lower amount – that fall into two distinct groups: slow twitching (type I fibres) and fast twitching (type II fibres). Type I muscles utilise the oxygen in your body better to generate more fuel, also known as adenosine triphosphate (ATP). They can take extra strain and, more often than not, fatigue slower. Type II muscles, on the other hand, are the opposite. Not needing oxygen to generate fuel, they create spurts of



strength and exhaust far quicker. The distinctions are similar to that of a marathon runner and a sprinter, with the former relying on their muscles taking longer to break down and the latter using the intensity and force of the faster twitching fibres to peak quickly.

It's these processes that allow us to both manipulate a muscle and make it stronger. Every time that you lift a weight you're tearing these muscle fibres apart, forcing the body to repair them. Once they're healed, the fibres are thicker than before, a process that can be manipulated with the right diet. Bodybuilders get protein into their system as soon as possible after a workout, as the substance is broken down into amino acids that are used to produce and repair muscles.

Your diet can even influence how effective this is: fast-acting carbohydrates play an important role in spiking insulin levels, which in turn replace muscle glycogen (reserve source of glucose) used during training. Such a process will also filter protein where it's needed, for maximum recovery and growth. This is why muscles get bigger and stronger with rest, and not at the gym where you're in fact breaking and destroying them.

"Your body will remember how strong you are, even if you stop training"

These principles shift across in terms of how muscles get stronger, too. The notion that lifting heavy weights at a lower rep range will increase body mass, whereas doing the opposite will make the muscle more visible, is a myth. Instead, when you train with heavy weights and force your muscles to expend all their ATP, you put the body in a state to recruit more muscle fibres and stimulate those that are missed when focusing on lighter weights. You're essentially teaching your muscles that they can become stronger. It won't suddenly make them bigger, but it will activate more fibres that in turn help you lift more. This type of training produces a form of muscle hypertrophy, which, in this instance, is increasing the size of your muscle cells. Hypertrophy can be manipulated to both boost muscular strength or simply focus on increasing body mass.

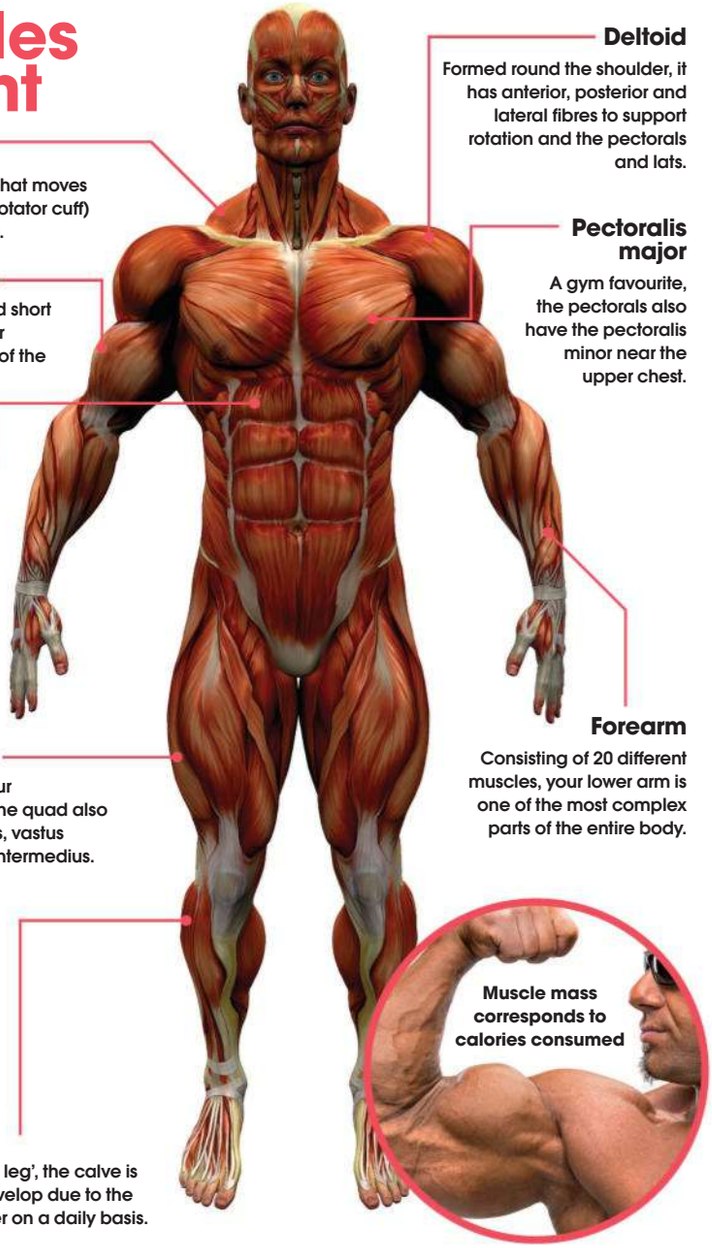
Your body will also remember how strong you are, even if you stop training. Although you'd have to work back up to your previous level, it would take half the time thanks to muscle memory. Just as we remember to perform everyday tasks, your muscles get used to the same movement and adapt accordingly.

The bigger they are...

Just because you look like The Hulk doesn't mean you're going to have the comic book character's strength. If you lift heavy weights for a low number of repetitions, you're training the muscle to take a more intense load due to the formation of new fibres. That doesn't mean you'll have the size to back it up, however, as mass corresponds to the number of calories consumed. The more food that's eaten, the quicker and more efficiently the muscle will be repaired. This is why plenty of power lifters who can pick up an incredible amount don't look like bodybuilders. Not only do they concentrate on pure strength, they also consume a massive number of calories. A bodybuilder, meanwhile, will sculpt his diet to shape and increase muscle size.

Not as strong as you might think...

Muscles in front



Trapezius
A superficial muscle that moves the scapulae (in the rotator cuff) and supports the arm.

Biceps brachii
Consists of a long and short head to, among other things, allow rotation of the forearm and elbow.

Rectus abdominis
Known to the greater world as 'abs' or a 'six-pack', it is possible to possess an eight-pack, or even ten-pack.

Vastus lateralis
The largest part of your quadriceps muscle, the quad also has the rectus femoris, vastus medialis and vastus intermedius.

Gastrocnemius
Meaning 'stomach of leg', the calve is incredibly hard to develop due to the pressure it is put under on a daily basis.

Deltoid
Formed round the shoulder, it has anterior, posterior and lateral fibres to support rotation and the pectorals and lats.

Pectoralis major
A gym favourite, the pectorals also have the pectoralis minor near the upper chest.

Forearm
Consisting of 20 different muscles, your lower arm is one of the most complex parts of the entire body.

Shoulders
Exercise name: **Military press**

How to do it: Using weights, bend your legs, lift up the bar in line with your shoulders and push from your deltoids until your arms are straight. Repeat.

Details: With the correct weight and intensity, it'll tear many muscles apart and increase your strength.

Strength rating:

Mid-section
Exercise name: **Side plank**

How to do it: Lay on your side and hoist your body up using the leg and arm you're resting on. Hold this position for as long as you can.

Details: The side plank will trigger both abdominals and mid-section, for a more efficient centre of gravity.

Strength rating:

Calves
Exercise name: **Calf raise**

How to do it: Using a Smith machine, stand under the barbell and place it on your trapezius muscles. Push from calves and stand on your tiptoes.

Details: Extremely difficult to enhance, the calf raise when done with a barbell will target this muscle.

Strength rating:

Chest
Exercise name: **Bench press**

How to do it: Lie on a bench and grab a barbell, hands about shoulder width. Bring the bar to chest level and lower until arms are at 90°. Push upwards.

Details: The bench press isn't merely beneficial for your chest; it also works your shoulders and triceps.

Strength rating:

Biceps
Exercise name: **Bicep curl**

How to do it: Raise a dumbbell from your side up to your shoulder rotating the arm so the palm with the weight faces up. Then lower and repeat.

Details: The biceps' relatively small size compared to other muscle groups means they're quite easy to target.

Strength rating:

Forearms
Exercise name: **Hammer curls**

How to do it: Hold a dumbbell in each hand with palms facing your body. Curl the weight up to your chest, keeping elbows locked. Lower down.

Details: Performed with a heavy weight, you can improve your grip and increase arm strength.

Strength rating:

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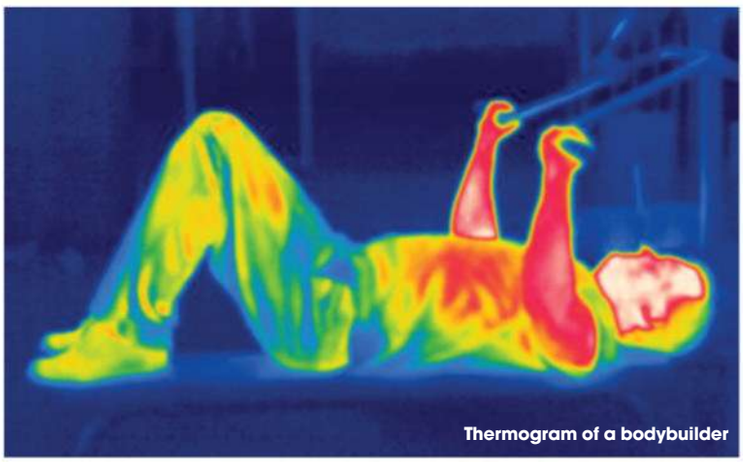
Inside muscle contractions

A muscle contracts when a fibre is kicked into gear as tension is put upon it. Myofibrils, which are found within a fibre, are made up of actin and myosin. When these two threads join the myofibril shortens, or contracts. If you straighten your arm, keeping your palm facing up, and measure the length of your bicep muscle, you'll find it will become a lot smaller if you curl your hand towards the shoulder.

There are many types of contractions, though. Isometric contractions occur when the angle of the joint or length of muscle do not change, say holding a dumbbell at arm's length and fighting the resistance. Such exercises are usually adapted to increase strength.

Isotonic contractions are the opposite and also more common, like traditional weightlifting where, as mentioned, muscle shortens with contraction. Though this can also be used for strength training, it's beneficial for expanding muscle size.



Thermogram of a bodybuilder

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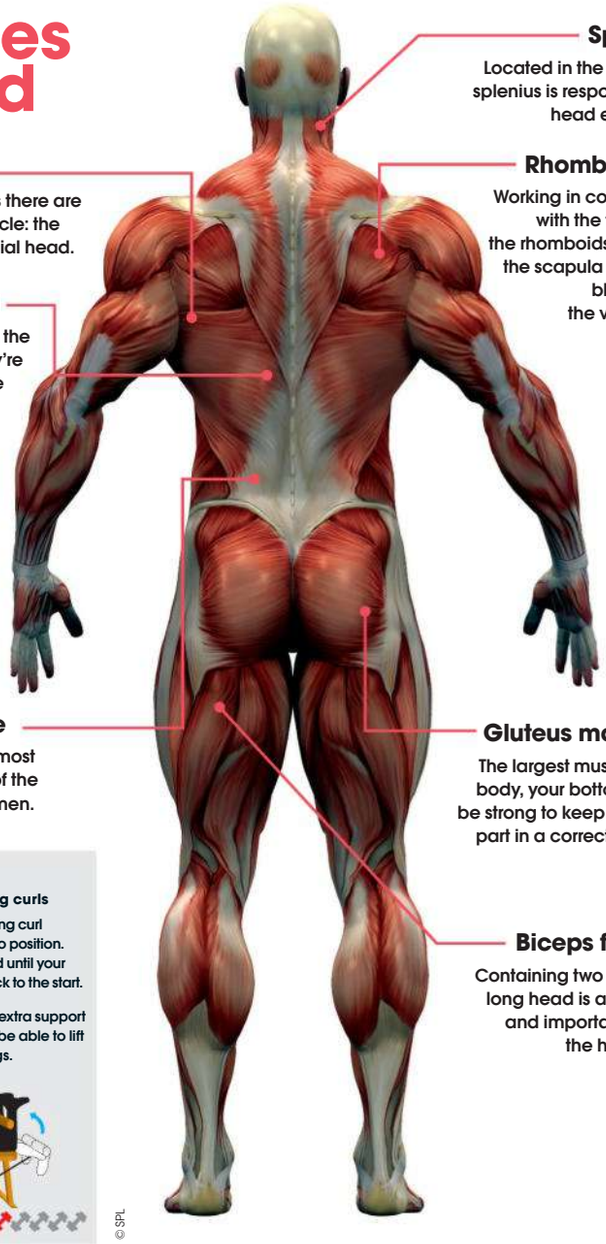
Muscles behind



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Splenius
Located in the neck, the splenius is responsible for head extension.

Triceps
As the name suggests there are three parts to the muscle: the long, lateral and medial head.

Rhomboideus
Working in conjunction with the trapezius, the rhomboids connect the scapula (shoulder blade) with the vertebrae.

Latissimus dorsi
Meaning 'broadest of the back', the lats, as they're commonly called, are an essential muscle for strengthening the entire body.

External oblique
The largest and outermost of the three muscles of the lateral anterior abdomen.

Gluteus maximus
The largest muscle in the body, your bottom has to be strong to keep the lower part in a correct position.

Biceps femoris
Containing two parts, the long head is an integral and important part of the hamstring.

Hamstrings
Exercise name: **Hamstring curls**

How to do it: Use a hamstring curl machine and lock legs into position. Push against the foam pad until your legs are at 90° and go back to the start.

Details: Curls will provide extra support to squats, meaning you'll be able to lift more weight from your legs.

Strength rating:

Upper arms
Exercise name: **Tricep kickback**

How to do it: Take one dumbell and hold it by your side. With the elbow locked pointing to the ceiling, extend your arm behind you till it's straight.

Details: Tricep extensions hit the three different heads that make up a large part of the upper arm at once.

Strength rating:

Back
Exercise name: **Deadlift**

How to do it: Lay barbell on the floor. Put shins to the bar, bend knees and push from the legs. When bar passes hips, straighten back and stand up.

Details: The deadlift utilises every muscle in your body, from your back to your hamstrings.

Strength rating:

Quadriceps
Exercise name: **Squats**

How to do it: Using barbell in a squat rack, place bar on trapezius. Back straight, bend knees until hamstrings parallel with floor. Push from legs.

Details: Squats target all of your leg muscles, as well as most of your upper ones too.

Strength rating:

Hysterical strength – fact or fiction?

Believe it or not, on occasion a desperate mother has found the strength to lift a car to save her threatened child. Seems impossible, right? Although there's no scientific evidence to support it, the most common theory is that the rush of adrenaline from the situation increases muscle twitching, enabling the recipient to be stronger and work harder for a very short period of time. When such an event occurs, though, what you don't hear about is the damage and injuries that these heroes usually suffer. It's why the body produces lactic acid in most cases, in order to stop the body from overdoing it.

Wheys and means

Many bodybuilders will supplement their diet with nutritional products – or even illegal drugs – to enhance their physique. Discover these common methods of bulking up...

Whey protein
A must for anyone trying to increase size/strength, getting enough protein is crucial. Not only is it the building block for muscles – amino acids construct protein which then builds muscle – but eating enough (usually around 1.5-2.0g per lb of bodyweight) will see the body start to grow.

Creatine
A natural substance already found in the body, creatine is an amino acid compound that stores energy. Supplementing with creatine can stop ATP levels (the substance that starts to drain when muscles are contracted) from depleting as quickly, meaning you can lift more weight for longer.

Anabolic steroids
Ranging from injectables – such as pure testosterone which enables the body to grow beyond its means – and orals, steroids enter the muscle cells and stimulate them, which increases their production. Due to this, more cells will be developed, making the body bigger.

Testosterone can be injected

What's inside your head

A look at how our thinking machines are put together

From birth, the head of a baby will grow very rapidly. By the age of two the bones will have fused together, although growth continues until the age of seven during which the shape and size of the skull are altered. An adult human head is made from 22 bones. Eight are present in the cranium, and 14 form the face. Together they make the skull, which provides a framework for all the features of our head.

The primary purpose of the skull is to prevent damage to the brain. Without it, even a small force against the head could cause serious brain damage. Before birth, the skull develops holes in which are found the various features of the head.

The skull has three main structural features. Cavities known as orbits contain the eyes, providing protection but also allowing muscles, nerves, blood supply and tissue to reach the eyes. Paranasal sinuses house the nasal cavity and also contain air-filled spaces, which are responsible for making people sound different. Finally, the head is held together by sutures, which are soft fibres at birth but later harden to give the appearance of stitches. They become immovable joints which stop the head falling apart.

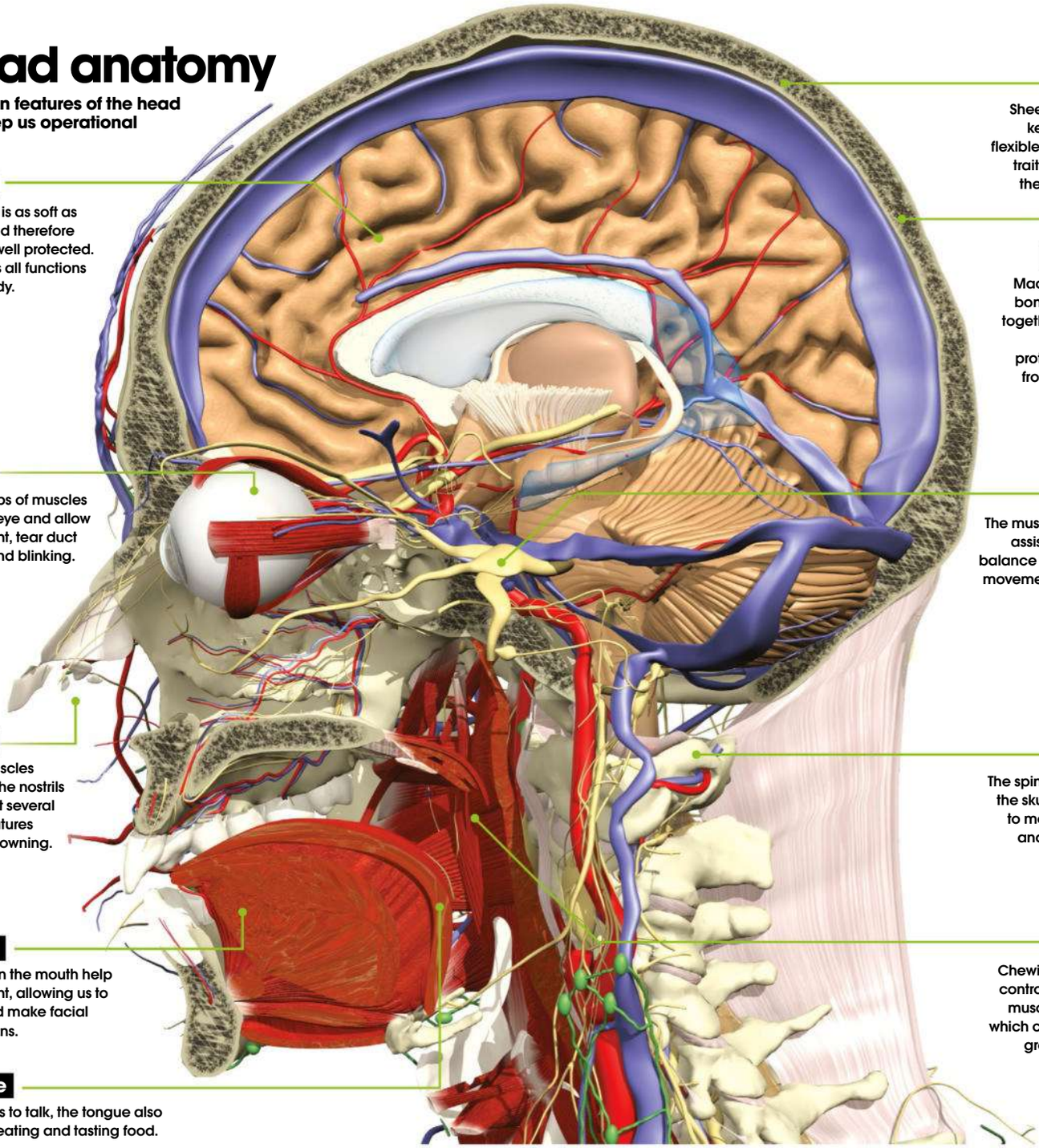
The muscles of the head are stretched over the bones in the cranium and face like sheets. There are two main categories of muscles. The muscles of facial expressions are responsible for moving the mouth, altering the chin and moving the cheeks to assist eating and breathing. Muscles of mastication directly control eating, opening and closing the jaw and allow sideways movements.

Smaller muscles control other portions of the face including the inner ear and the eye.

© Getty

Head anatomy

The main features of the head that keep us operational



Brain
The brain is as soft as butter, and therefore must be well protected. It controls all functions in the body.

Eyes
Two groups of muscles hold the eye and allow movement, tear duct control and blinking.

Nose
Nasal muscles operate the nostrils and assist several facial features such as frowning.

Mouth
Muscles in the mouth help movement, allowing us to chew and make facial expressions.

Tongue
Helping us to talk, the tongue also assists in eating and tasting food.

Scalp
Sheet-like muscles keep our scalps flexible, an important trait for nourishing the skin and hair.

Cranium
Made of eight flat bones and joined together by sutures, the cranium protects the brain from bumps and knocks.

Ears
The muscles in the ear assist hearing and balance but allow little movement of the ears.

Spine
The spine connects to the skull, allowing us to move our heads and look around.

Jaw
Chewing is primarily controlled by strong muscles in the jaw, which can produce a great amount of pressure.

What's a knockout?

When the head is struck hard enough, a person can become unconscious. This can cause long-lasting head injuries and must be treated immediately. As the head is struck, the brain processes all the information it receives from the sensory nerves to formulate an appropriate response, be it forcing the person to withdraw, pushing their aggressor or holding the injured area. However, the brain also has a limit on how much it can process, and a hard enough blow may overload it with information.
To prevent any further damage to the hea d, the brain stops communicating with the body, causing unconsciousness. Although it may seem similar to sleep, an unconscious person will not respond to people or noises and will only wake up once the brain begins communicating with the body again.

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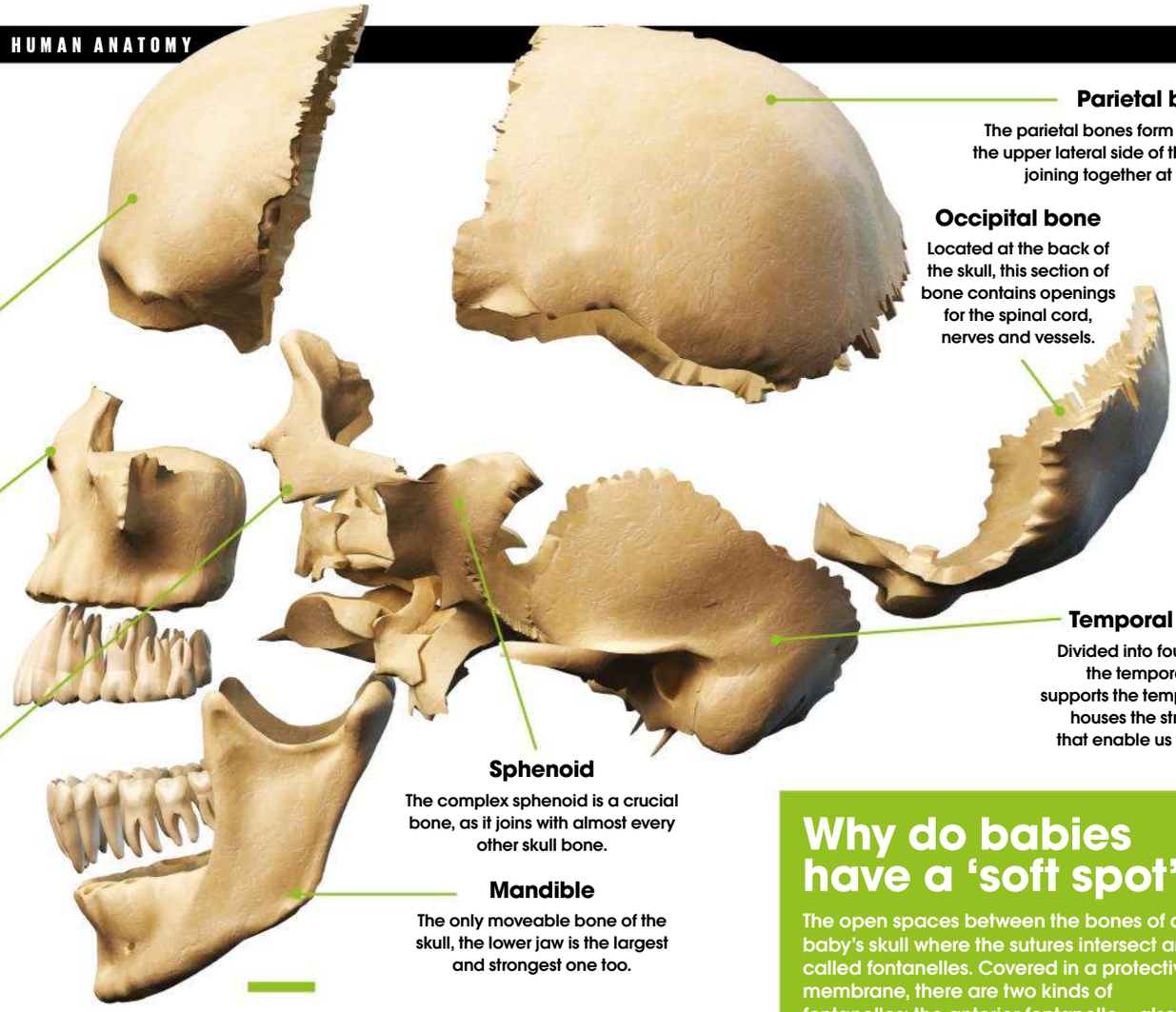
Breaking it down

How the various bones fit together to form the skull



The human skull

Understand the complex structure that supports our brain and facial tissues

The human skull is made up of 22 bones that fall into two primary groups: the cranium, which consists of eight 'cranial' bones, and the facial skeleton, which consists of 14 facial bones. These bones are joined together by fibrous joints known as sutures. Unique to the skull, once these joints have fused together by the age of around 30 to 40, they are immovable.

The cranium consists of a roof part – known as the calvarium – and a complex base part. The calvarium helps to cover the cranial cavity, which the brain occupies, along with flat bones at the top and sides. The base of the brain case is divided into large spaces, and has various openings for the passages of cranial nerves, blood vessels and the spinal cord.

The facial skeleton provides support for the soft facial tissues, and its bones fuse together to house the orbits of the eyes, nasal and oral cavities, in addition to the sinuses. Only one of the skull's 22 bones is moveable, and that is the lower jaw.

As you can see in the diagram above, the skull is a complex structure, but then its main roles are to protect the brain and support the face, so this comes as no surprise.

The skull does an impressive job of protecting superficial muscles, nerves and blood vessels

Why do babies have a 'soft spot'?

The open spaces between the bones of a baby's skull where the sutures intersect are called fontanelles. Covered in a protective membrane, there are two kinds of fontanelles: the anterior fontanelle – also known as the 'soft spot' – and the posterior fontanelle. The anterior fontanelle is where the two frontal and two parietal bones meet, and this area stays soft until the age of around two. The posterior fontanelle is where the two parietal bones and the occipital bone meet, and this area usually closes when a baby is a few months old.

The formation occurs as a means of helping the baby's head fit through the birth canal. The reason they remain open for some time is to enable the brain to develop and grow. It's important that the fontanelles don't close up too early – a process known as craniosynostosis – as this can result in various medical problems.

The anterior fontanelle is positioned at the front of the skull

Anatomy of facial expressions

Does it really take more muscles to frown than to smile?

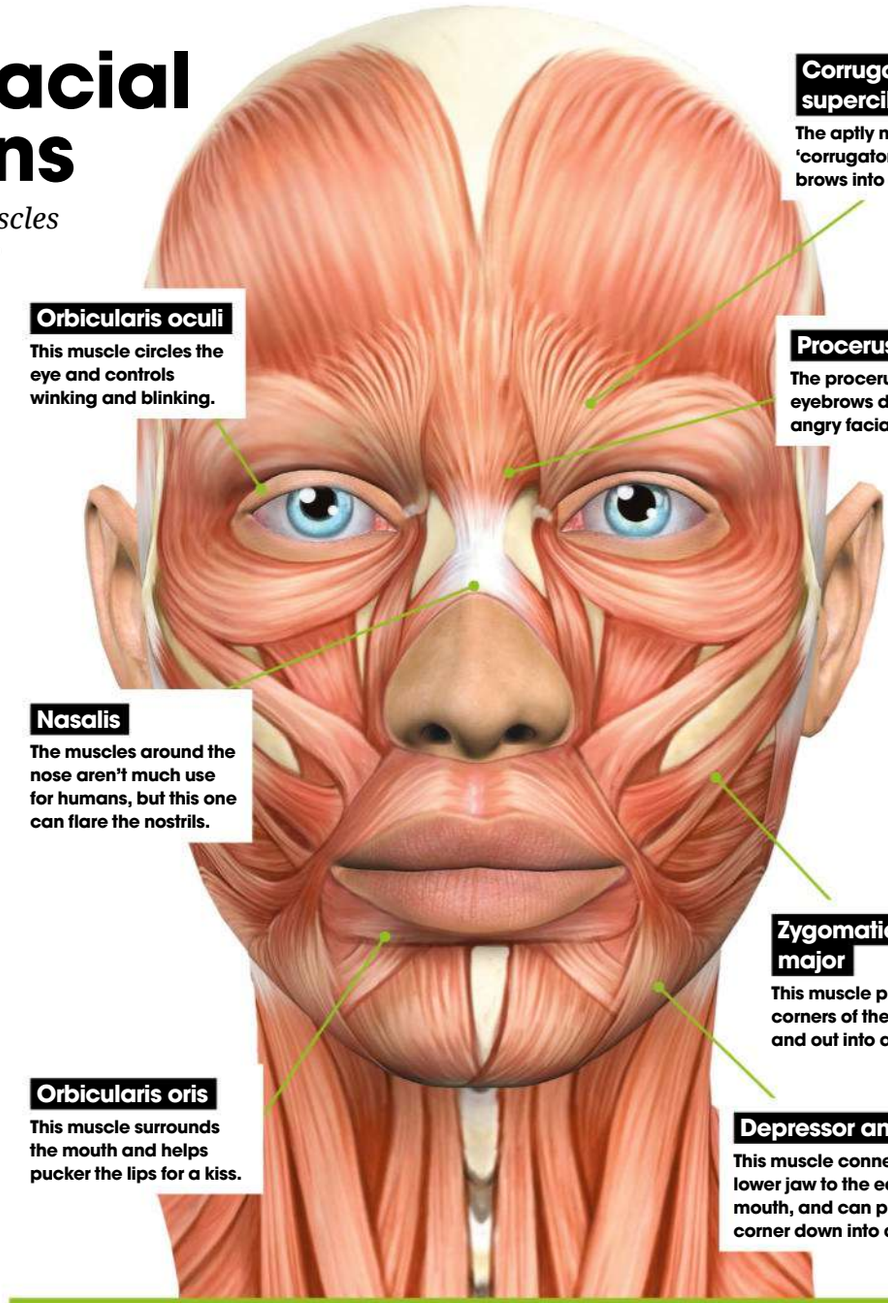
The 43 muscles of the face are attached to bone, or sheets of tissue known as fascia, at one end, and – unlike any other muscles in the body – they join directly to the skin at the other.

There are three groups of facial muscles: orbital, nasal and oral. Together, they enable us to make four core expressions: happy, sad, afraid and angry, and over 20 combined expressions.

There are two muscles in the orbital group – the orbicularis oculi, which surrounds the eye socket, and the corrugator supercilii, which controls the eyebrow. The first is responsible for blinking and winking, and the second contracts to pull the eyebrows together into a frown.

We don't have a lot of control over the nasal group but the biggest, the nasalis, flares the nostrils with help from the depressor septi. The procerus runs from the top of the nose to the forehead, and pulls the eyebrows down.

Finally, there are the oral muscles. The two major ones are the orbicularis oris, which surrounds the mouth and contracts to purse and pucker the lips, and the buccinator running under the cheekbone. There are also two groups of smaller muscles, the upper and the lower groups, which control the fine movements of the facial tissue to form smiles and frowns.

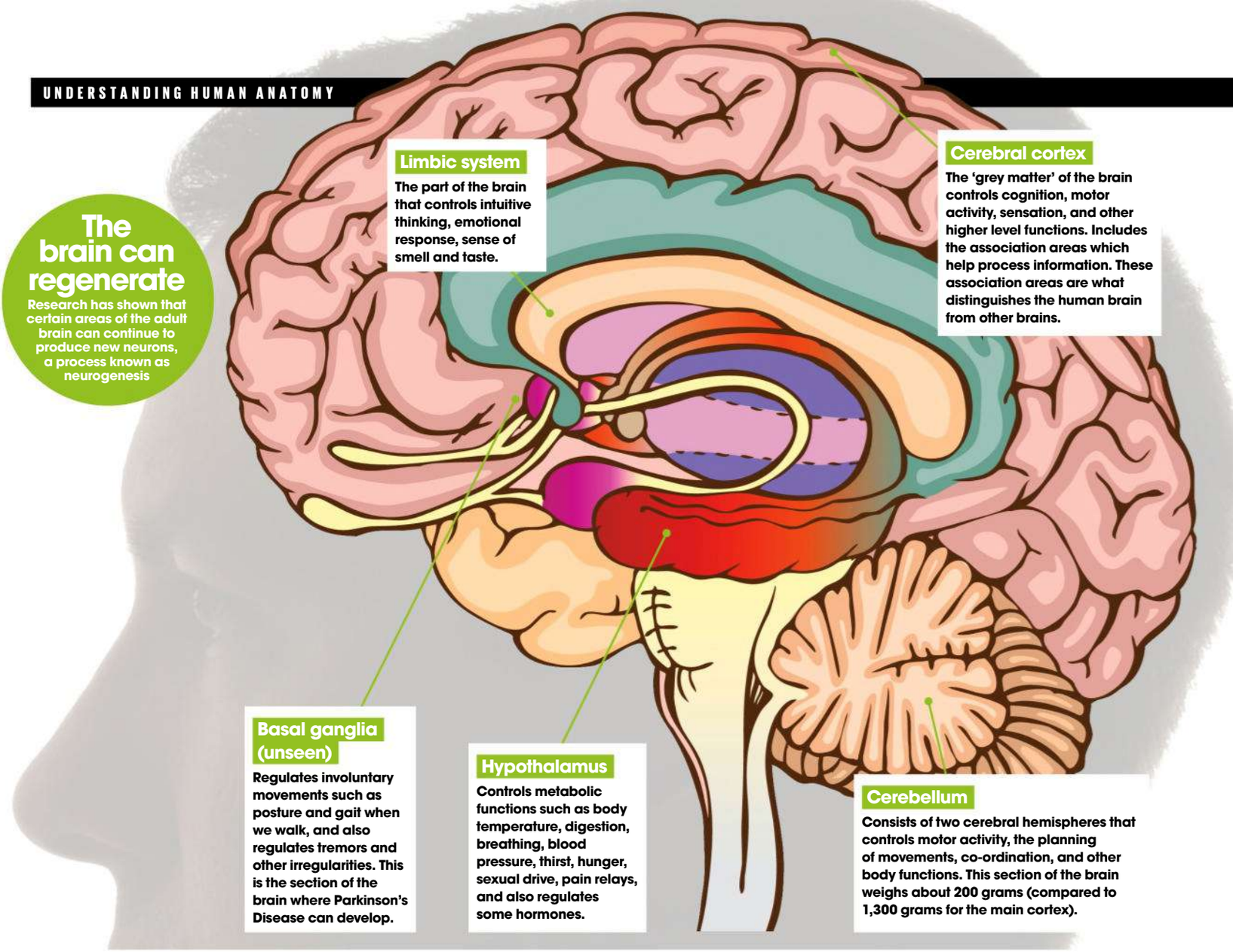


Deciphering the face

Benjamin Amand Duchenne was a French physiologist in the 19th century, and his macabre experiments attempted to reveal the muscles responsible for different facial expressions. He wired test subjects up to galvanic probes, which delivered small electric shocks through the skin to the underlying muscles. He tried his experiment on five test subjects: a girl, a young man and woman, and an older man and woman. He captured pictures of the expressions made when different parts of the face were stimulated. Charles Darwin was so taken with the images that he later used them in his own experiments to find out whether people could read the emotions of the test subject just by looking at the expressions that their faces were pulling.

This photo shows Duchenne's experiment in action

© Phototake: WIKI



The brain can regenerate

Research has shown that certain areas of the adult brain can continue to produce new neurons, a process known as neurogenesis

The human brain

Described as the most complex thing in the universe, our brains are truly astonishing

The brain makes up just two per cent of our total body weight, but crammed inside are approximately 86 billion neurons, surrounded by 180,000 kilometres of insulated fibres connected at 100 trillion synapses. It's a vast biological supercomputer.

The cells in the brain communicate with each other using electrical signals. When a message is sent, thousands of microscopic channels open, allowing positively charged ions to flood across the membrane. Afterwards, more than 1 million miniature pumps in each cell will move the ions back again, ready for the next impulse.

The cell bodies of the neurons, and their connections, are contained within the grey matter, which consumes 94 per cent of the oxygen delivered to the brain. Different areas are responsible for different functions, and wiring them together is a fatty network of fibres called white matter.

When a signal reaches the end of a nerve cell, tiny packets of chemical signals will spill out onto the surrounding neurons. These connections, called synapses, allow messages to be passed from one cell to the next. Each neuron can receive thousands of inputs, coordinating them in time and space, and by type of chemical, to decide what to do next.

Scientists have been electrically and chemically stimulating the brain to see how it responds to different signals, recording electrical activity to map thoughts and using imaging like functional MRI to track the blood flow increases that reveal when nerve cells are firing. The cells of the brain can also be studied inside the lab. Thanks to these investigations we know more about this incredible structure than ever before, but our understanding is only just beginning.

Brain development

From a single cell to an incredibly intricate network in just nine months

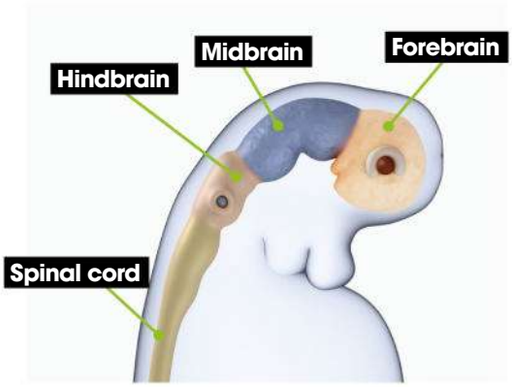
Within weeks of fertilisation, neural progenitors start to form; these stem cells will go on to become all of the cells of the central nervous system. They organise into a neural tube when the embryo is barely the size of a pen tip, and then patterning begins, laying out the structural organisation of the brain and spinal cord. At its peak growth rate, the developing brain can generate 250,000 new neurons every minute. By the time a baby is born, the process still isn't complete. But, by the age of two, the brain is 80 per cent of its adult size.

Pyramidal neurons, like these, are found in the hippocampus, cortex and amygdala

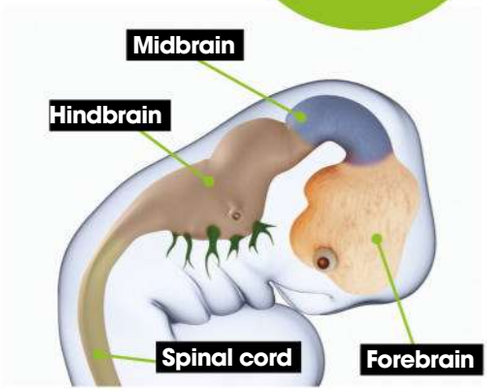
20 watts
Your brain is incredibly efficient, using less energy than a standard lightbulb

Brain formation

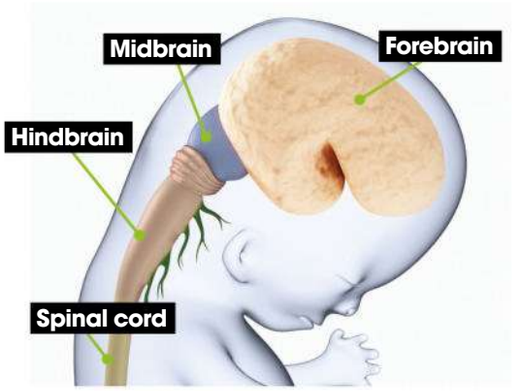
This astonishing structure is formed and refined as pregnancy progresses



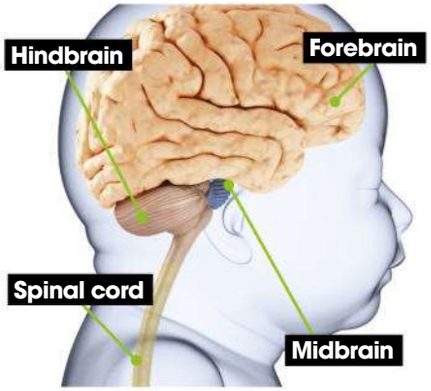
4 weeks
Brain development starts just three weeks after fertilisation. The first structure is the neural tube, which divides into regions that later become the forebrain, midbrain, hindbrain and spinal cord.



6 weeks
The pattern of the brain and spinal cord is now laid out and is gradually refined, controlled by gradients of signalling molecules that assign different areas for different functions.



11 weeks
As the embryo becomes larger, the brain continues to increase in size and neurons migrate and organise. The surface of the brain gradually begins to fold. At this point, a foetus only measures about five centimetres in length.



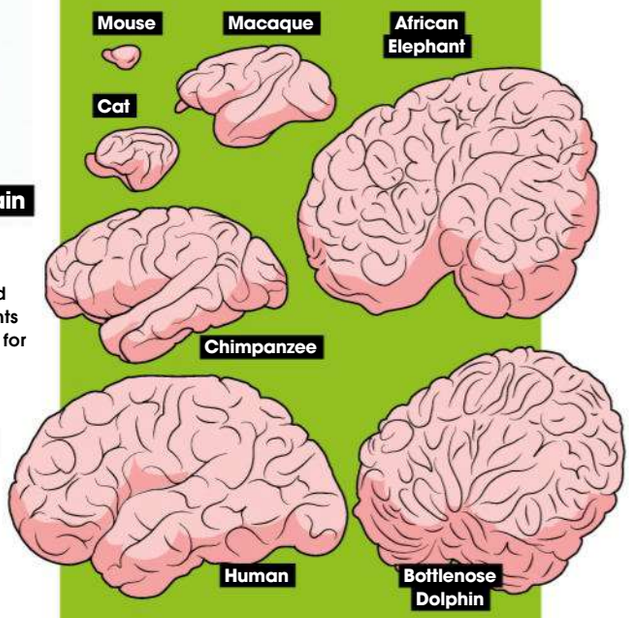
Birth
Before a baby is born, around half of the nerve cells in the brain are lost and connections are pruned, leaving only the most useful. This process continues after birth.

Why the brain is wrinkled

The brain folds in on itself to cram in more processing power

The folds and pockets of our brains are a biological rarity that we only share with a few other species, including dolphins, some primates and elephants. It's a clever evolutionary adaptation that allows intelligent species to squash a huge amount of cortical tissue into a small space, allowing enormous brainpower to be crammed into our relatively small skulls.

Folding starts during the second trimester of pregnancy, creating ridges (gyri) and fissures (sulci), but the biology behind the distinctive wrinkles is stranger than you might think. The organisation of the brain is determined by complex cascades of chemical signals, but the overall shape seems to be the result of simple physics. Grey matter sits on the outside of the brain and, during development, its growth rapidly outpaces the growth of white matter underneath. This puts mechanical stress on the structure, forcing the outside to buckle and curl.



More wrinkled brains are associated with higher intelligence (brain sizes not to scale)

"Our brains contain 86 billion neurons and 180,000 kilometres of fibres"

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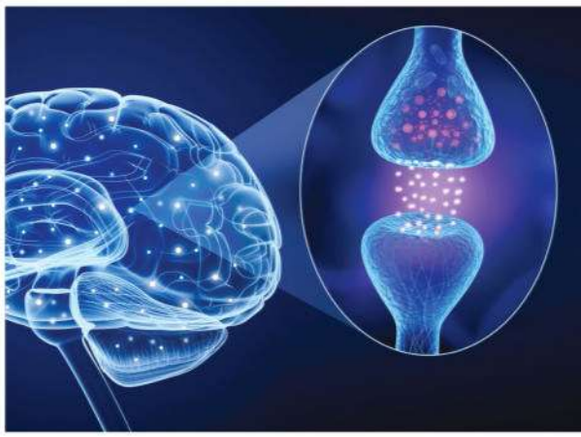
Making memories

The brain can store around 1 million gigabytes of data

A team at the Salk Institute in California estimate that the brain can store around 1 petabyte of information, stuffed into the connections between nerve cells. That's around 2,000 years worth of MP3 music or 223,000 DVDs. And, incredibly, it's possible to watch memories being made.

The Weizmann Institute in Israel and UCLA in the US captured memory formation in action. Patients watched clips of videos and were then asked to recall what they'd seen. The neurons that lit up when they watched the first time lit up again as they relived the experience inside of their heads – a bit like an echo in the brain.

Recent research from the US and Japan suggests that these echoes are actually stored twice – once in the hippocampus and again in the cortex. The hippocampus handles short-term storage and gradually forgets, but as it does so it helps to reinforce the memory in the cortex, allowing long-term recall.



Neurons make new connections when a memory is formed

Self-cleaning brains

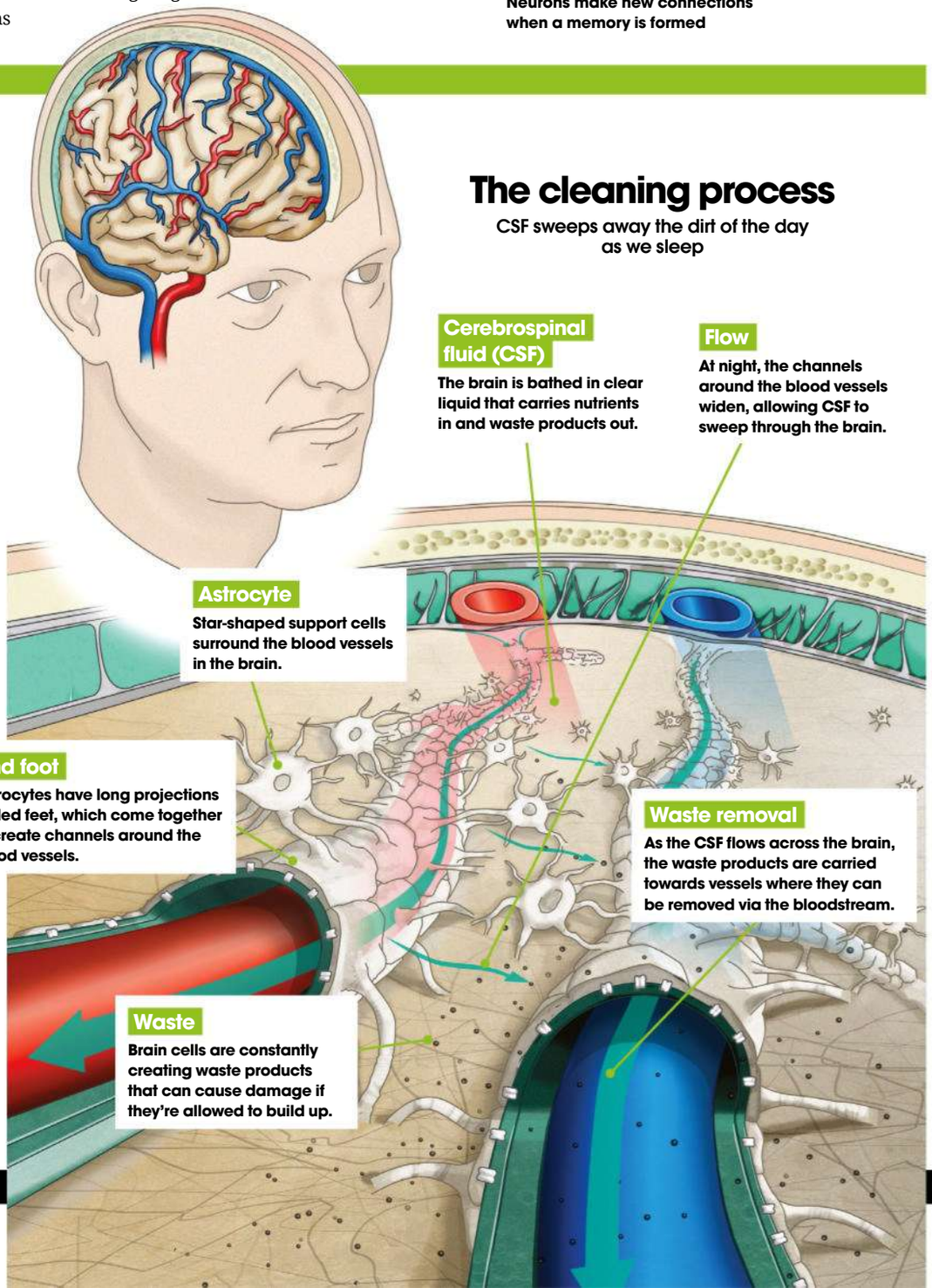
We have a built-in system to clear toxic waste from between our brain cells

Sleep is one of the brain's great mysteries, but research on mice has revealed an intriguing night time cleanup system. The brain is shielded by a barrier made and maintained by cells called astrocytes. They hug the blood vessels, controlling what's allowed in and out, and a space between the vessel wall and these cells seems to play a crucial role in keeping the brain clean.

At night, the astrocytes relax their grip and the space fills up with a clear liquid called cerebrospinal fluid (CSF). It's pushed along by the movement of the blood vessels underneath, swishing up through the astrocytes and out into the spaces between brain cells. As it passes, it picks up waste and debris, carrying the particles back towards the bloodstream so that they can be removed from the brain.

The cleaning process

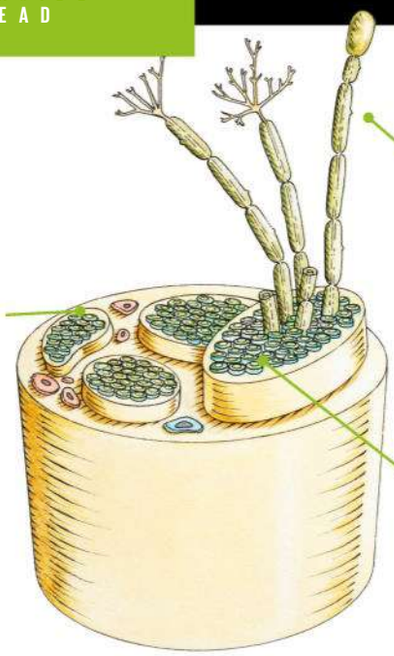
CSF sweeps away the dirt of the day as we sleep



How do nerves work?

Nerves carry signals throughout the body – a chemical superhighway

Nerves are the transmission cables that carry brain waves in the human body, says Sol Diamond, an assistant professor at the Thayer School of Engineering at Dartmouth. According to Diamond, nerves communicate these signals from one point to another, whether from your toenail up to your brain or from the side of your head.



Myelinated and un-mylinated

Some nerves are myelinated (or insulated) with fatty tissue that appears white and forms a slower connection over a longer distance. Others are un-myelinated and are un-insulated. These nerves travel over shorter distances.

Nerve transmissions

Some nerve transmissions travel great distances through the human body, others travel short distances – both use a de-polarisation to create the circuit. De-polarisation is like a wound-up spring that releases stored energy once triggered.

Nerve triggers

When many neurons are activated together at once, the nerve is excited: this is when we might feel the sensation of touch or a distinct smell.

© DK Images

What does the spinal cord do?

The spinal cord actually is part of the brain and plays a major role in the body

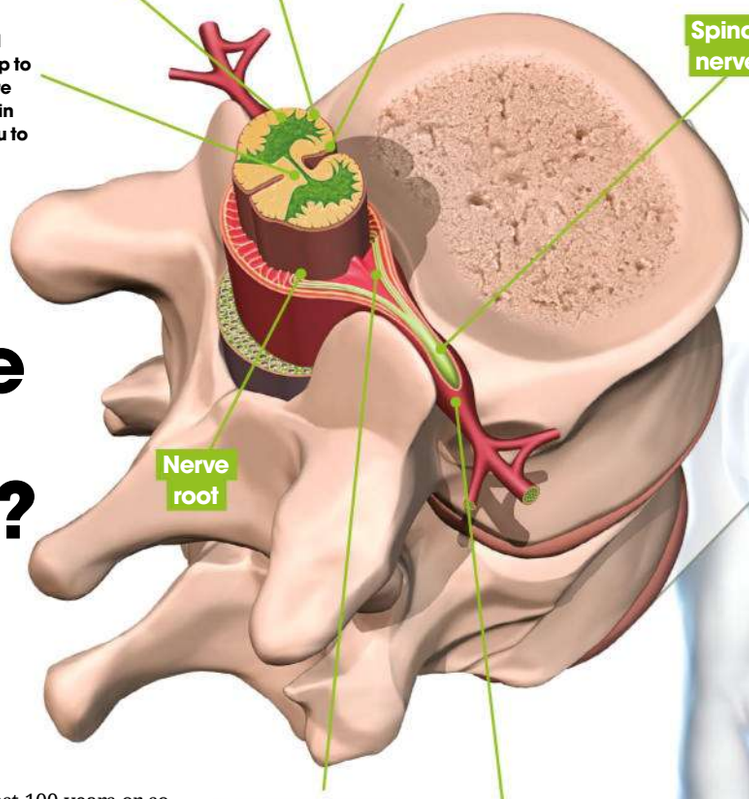
Scientists have known for the past 100 years or so that the spinal cord is actually part of the brain. According to Melillo, while the brain has grey matter on the outside (protected by the skull) and protected white matter on the inside, the spinal cord is the reverse: the grey matter is inside the spinal cord and the white matter is outside.

Grey matter cells

Grey matter cells in the spinal cord cannot regenerate, which is why people with a serious spinal cord injury cannot recover over time. White matter cells can re-generate.

White matter cells

White matter cells in the spinal cord carry the electro-chemical pulses up to the brain. For example, when you are kicked in the shin, you feel the pain in the shin and your brain then tells you to move your hand to cover that area.



Neuronal fibre tracts

Spinal cord core

In the core of the spinal cord, grey matter – like the kind in the outer layer of the brain – is for processing nerve cells such as touch, pain, and movement.

Spinal nerve

Nerve root

Neuroplasticity

In the spinal cord and in the brain, cells can rejuvenate over time when you exercise and become strengthened. This process is called neuroplasticity.

Neurogenesis

According to Tallal, by repeating brain activities such as memorisation and pattern recognition, you can grow new brain cells in the spinal cord and brain.

© Getty / iStock / Arrowhead Forensics

Neurotransmitters and your feelings

Are our moods and emotions really just brain chemistry?

Messages are passed from one nerve cell to the next by chemical messengers called neurotransmitters. Each has a slightly different effect and by looking at what happens when neurotransmitter levels change, we are discovering that different combinations play a role in a range of complex emotions.

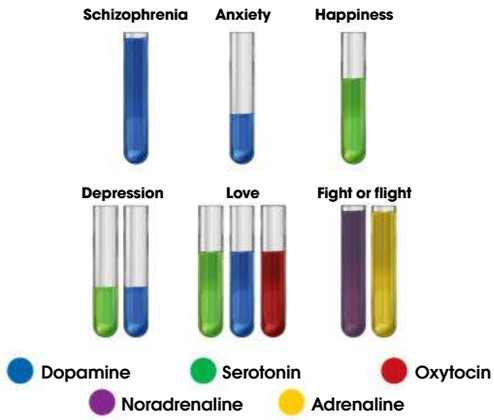
Acetylcholine excites the nerve cells that it touches, triggering more electrical activity. It plays a role in wakefulness, attention, learning and memory, and abnormally low levels are found in the brains of people with dementia caused by Alzheimer's disease.

Dopamine is a chemical that also excites nerve cells. It plays a vital role in the control of movement and posture, and low levels of dopamine underlie the muscle rigidity that exists in Parkinson's disease. Dopamine is also used in the brain's reward circuitry and is one of the chemicals responsible for the good feelings associated with addictive behaviour types.

Noradrenaline is similar in structure to the hormone adrenaline and is involved in the 'fight or flight' response. In the brain, it keeps us alert and focussed. In contrast, GABA reduces the activity of the nerves that it interacts with and is thought to reduce feelings of fear or anxiety.

Serotonin is sometimes known as the 'happy hormone' and transmits signals involved in body temperature, sleep, mood and pain. People with depression have been found to have lower serotonin levels than normal, though raising serotonin levels with antidepressant medications does not always help.

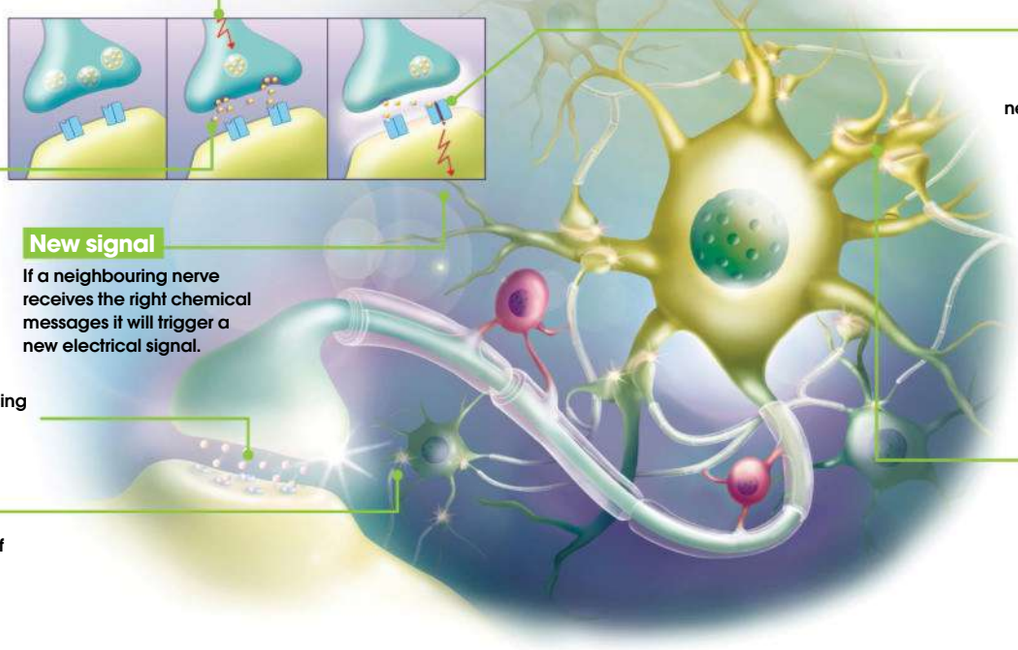
There are many more neurotransmittersas well as other chemicals like hormones that also influence nerve cells. It is these interactions that result in the vast range of human emotions.



Different levels of neurotransmitters have been associated with different mental states

The synapse

Neurotransmitters pass messages from one nerve cell to the next



Incoming signal
Neurotransmitter release is only triggered when there is enough electrical activity in the nerve cell.

Neurotransmitters
These chemical messengers travel across the small gap - called the synaptic cleft - and stick to receptors on nearby nerve cells.

New signal
If a neighbouring nerve receives the right chemical messages it will trigger a new electrical signal.

Synapse
Nerve cells communicate by releasing neurotransmitters at specialised junctions called synapses.

Part of a network
Each nerve cell makes thousands of connections to its neighbours and has its own mix of different neurotransmitters and receptors.

Receptor
Nerve cells can only respond to a specific neurotransmitter if they have the right corresponding receptors to detect it.

Feelings
The combined activity across this complex system is what underpins our thoughts, feelings and emotions.

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Brain cells

Find out what's really going on inside your head

Your brain is an incredible thing. It is one of the most complex structures in the known universe, and for decades, scientists have been teasing it apart to find out what it's made of and how it works.

The brain is an electrical and chemical circuit, and nerve cells, or neurons, are the components. They each have a cell body, which contains their genetic code, an axon to transmit electrical impulses, and dendrites to receive them.

They are connected together at junctions known as synapses. When an impulse arrives, packets of molecules are released, passing the message on. Each neuron makes hundreds, or even thousands, of connections, producing the complicated patterns that drive human thought.

There are hundreds of different types of neuron in the brain, categorised according to their unique structure and function, and more are being discovered all the time. But they can't function on their own. They are supported by a network of glial cells – a name that literally means 'glue'.

There are three main types of glial cell. Oligodendrocytes have fatty branches, which they wrap around the conducting axons of nerve cells like the plastic coating on electrical wires. This provides insulation, preventing signals from getting crossed and speeding up their transmission along the chain.

Microglia are part of the immune system and act like an in-house cleanup crew, tracking down pathogens and clearing debris from the brain. Then there's the star-shaped astrocytes, which reach between nerve cells and blood vessels with their long, thin arms, shuttling nutrients, mopping up waste products, and even getting involved with chemical signalling.

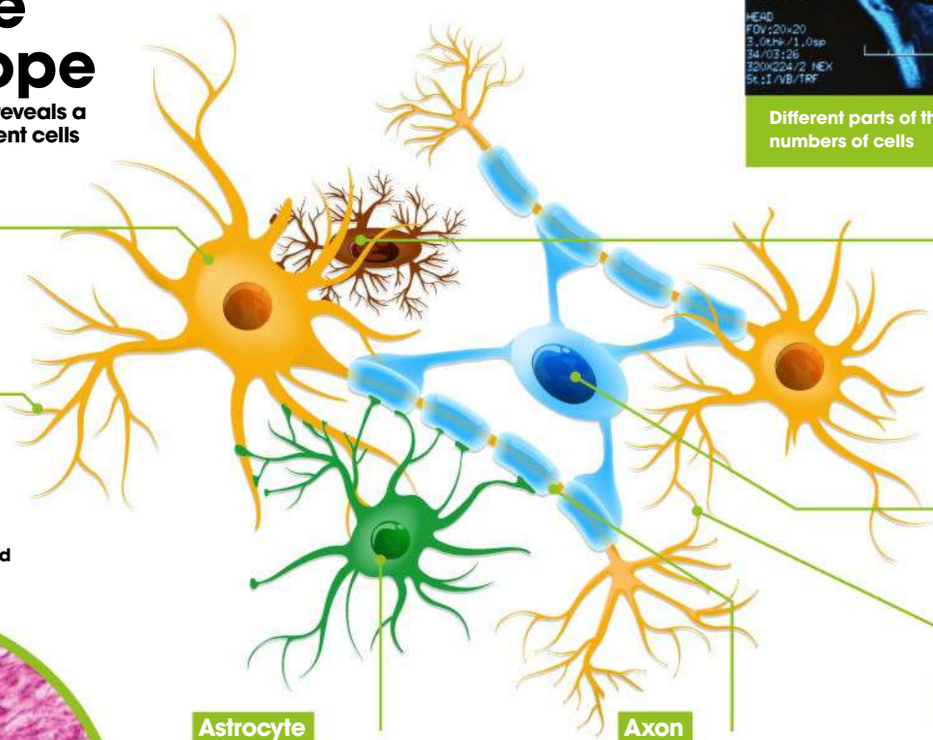
How many cells?

It's hard to know exactly how many cells are in the brain. Individual neurons have long, thin axons and branching trees of dendrites that cross over with their neighbours, forming a tangled mass that is almost impossible to accurately examine. One of the most commonly quoted estimates is 100 billion neurons, with anywhere between three and ten times as many supporting glial cells, but the latest research suggests that these numbers are in fact wrong. Using a new technique for counting cells, scientists have come up with a different number. Each cell has one nucleus, and they can be stained up to make it easy to tell whether they belong to a neuron or a glial cell. Rather than count them under a microscope, the researchers popped the cells open and turned them into a 'soup' so that they could be quickly counted by machine. Using this technique, they revealed that there are closer to 86 billion neurons and about the same number of glial cells – far fewer than expected.

Different parts of the brain contain different numbers of cells

Under the microscope

A closer look at the brain reveals a complex network of different cells



Neuron
These are the nerve cells, responsible for transmitting and receiving the electrical and chemical signals in the brain.

Dendrite
These branching processors receive thousands of incoming signals from other neurons.

Microglia
These are specialist immune cells, helping to keep the brain healthy and free from disease.

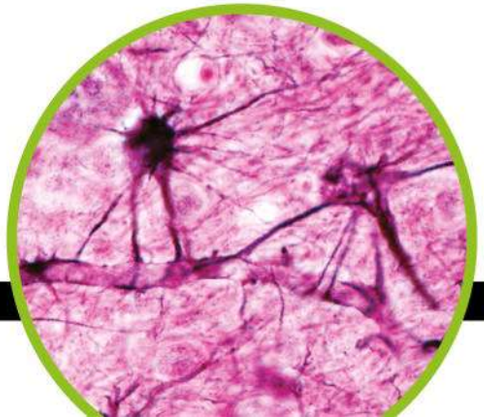
Oligodendrocyte
These cells provide insulation, wrapping fatty membranes around the neurons to speed up their electrical signals.

Synapse
Chemical signals are exchanged at these junctions, passing messages from one neuron to the next.

Axon
This part of the neuron transmits electrical signals towards neighbouring cells.

Astrocyte
These star-shaped cells support the neurons, providing nutrients, clearing waste and contributing to signalling.

This microscope image shows astrocytes grabbing on to blood vessels with their 'feet'



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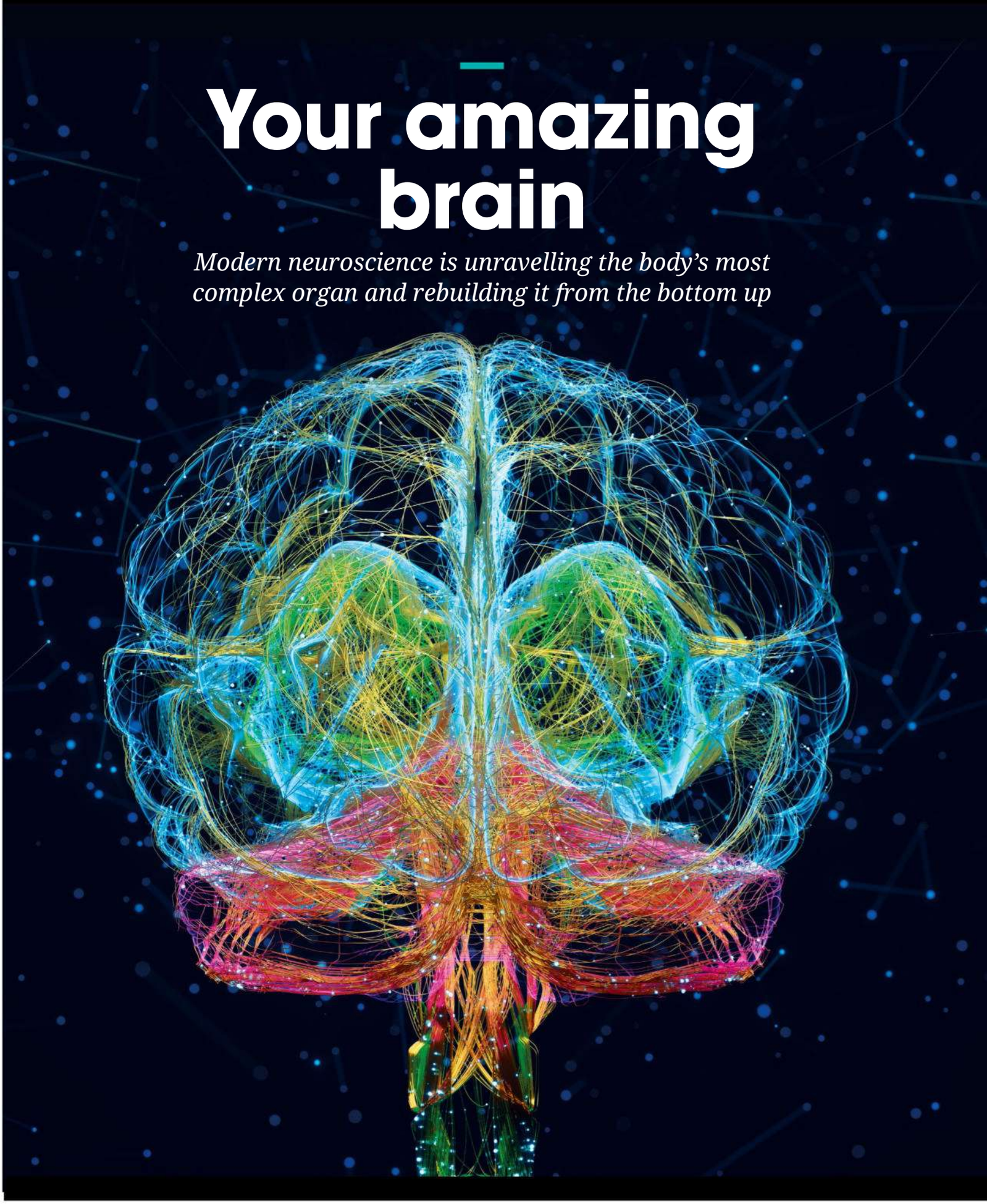
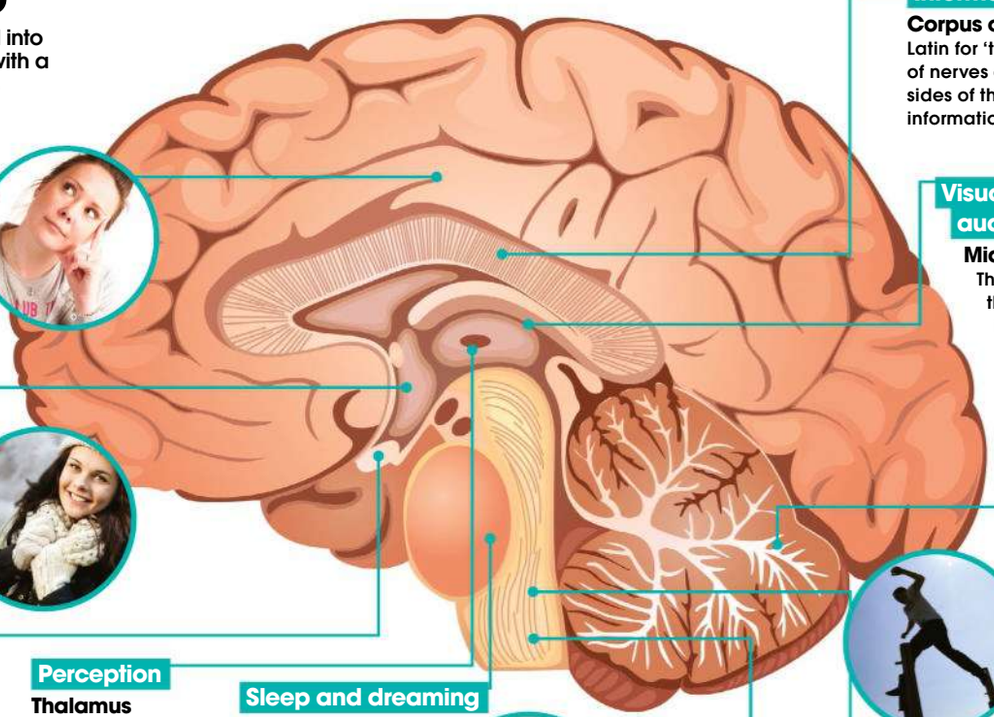
Your amazing brain

Modern neuroscience is unravelling the body's most complex organ and rebuilding it from the bottom up



Brain map

The brain can be divided into distinct structures, each with a specialist set of functions



Memory

Cerebrum
The cerebral cortex makes up the majority of the human brain. It is divided into four lobes, which handle the most complex of tasks, including planning, memory and vision.

Temperature and hydration

Hypothalamus
The hypothalamus is responsible for maintaining equilibrium within the body. It monitors and adjusts mechanisms like the body's temperature and hydration.

Hormones

Pituitary gland
This pea-sized gland is connected to the hypothalamus and produces hormones, passing on chemical messages instead of electrical impulses.

Perception

Thalamus
The thalamus is a switchboard for sensory information, connecting the parts of the brain and body involved in perception and movement. It also controls the sleep/wake cycle.

Sleep and dreaming

Pons
The pons is another relay station within the brain, allowing nerves in the cerebellum to contact those in the cortex. The pons also plays an important role in the sleep cycle and dreaming.

Breathing

Medulla
The medulla is responsible for the involuntary functions that keep us all alive, like breathing, swallowing and heartbeat.

Information transfer

Corpus callosum
Latin for 'tough body', this wide sheet of nerves connects the left and right sides of the brain, transferring information from one to the other.

Visual and auditory systems

Midbrain
The midbrain is buried near the centre of the brain and is home to part of the reward pathway, responsible for reinforcing positive behaviours and addiction.

Coordinated movement

Cerebellum
Cerebellum means 'little brain'. It is the control centre for coordinated movement, making fine adjustments before the signals are sent to the body.

Connects nerves

Brain stem
The brain stem marks the end of the brain and connects the nerves to the spinal cord. It contains two distinct structures, the pons and the medulla.

The human brain is the most complicated structure in the known universe. It has taken hundreds of millions of years of evolution to construct, and over the last seven million years, it has tripled in size. It weighs little more than a bag of sugar, but packed inside it are 86 billion neurons, linked together by over 100 trillion connections in a network more powerful than even the most advanced supercomputers ever built.

By far the largest part of the human brain is the forebrain, and like the brains of other mammals, it is covered in a thick layer of neurons known as the cerebral cortex. But in humans, this layer has been massively expanded – it has 1,000 times as many neurons as the same structure in a mouse, and it has not yet stopped evolving.

The smallest processing units in the cortex are known as neocortical columns, where each contains thousands of different connections. Over the course of evolution, these neocortical columns have been duplicated over and over again, until space in the skull started to run out. The cortex developed deep ridges and folds to fit more and more processing power into the same tiny space, and if unfolded, would cover an area measuring two square metres (21.5 square feet). The neurons that make up the brain crisscross over one another in a vast network and each individual cell makes up to 10,000 connections, building the most complex circuit in history.

In 2013, a team at the Centre for Regenerative Therapies in Dresden, Germany, examined the formation of neuron connections in cloned mice. They wanted to learn how much the structure of the brain is influenced by life experience. Because the mice were clones, each was genetically identical, meaning that any differences in their brains would be purely down to their environment. The mice lived in large cages, with lots of toys and places to explore, and after just a few months, differences became apparent in their brains. The most excitable, outgoing, curious mice had many more new nerves and new connections than their lazier counterparts; their brains had adapted as they learnt.

> **"While the underlying fabric of the brain is the same, every neuron in every brain is different"**

While the underlying fabric of the brain is the same, every neuron in every brain is different, and each makes its own unique path. Every brain is wired differently, and the unique set of connections is based on experiences.

Mapping the connections in the human brain is an enormous task and work is ongoing. The Human Connectome Project, launched in 2009, is designed to map the intricate connections between all of the neurons in the human brain,

in an effort analogous to the Human Genome Project. Computers can be programmed to trace the paths of neurons through brain-scan images, but even the most advanced machines make mistakes, and everything has to be double-checked by a human.

As an alternative, some research teams are trying a new approach: instead of using computers to analyse data, they use volunteers. In 2011, the online game Foldit made the headlines when players managed to solve a decade-old biological question. By tapping into the spatial skills of videogamers, researchers used volunteers to solve three-dimensional protein puzzles that a computer would struggle with. By playing the game, hundreds of people worked together to help solve the structure of a protein made by a simian retrovirus that causes AIDS-like symptoms in monkeys.

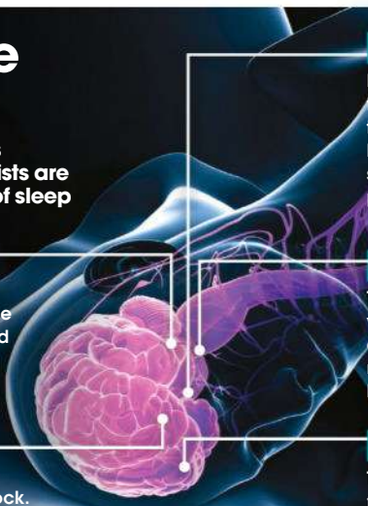
This approach is now being extended to the field of neuroscience and crowd-sourcing is being used to map the connections between neurons in the back of the eye. Tracking the intricate pathways of neurons in the brain is a difficult task for computers, but people are much better at spotting patterns.

EyeWire is a project designed to map the nerve connections in the human retina. Players are given a half-finished neuron and asked to work through slices of the brain, colouring in the connections. Each cube section is manually checked multiple times by different people, so if someone makes a mistake it is averaged out by the community. More experienced players oversee the work and can make changes if they feel they are needed. This approach speeds up the process by thousands of times.

Although projects like EyeWire provide a detailed and biologically accurate picture of what

The science of sleep

By monitoring the brain's electrical activity, scientists are unravelling the mystery of sleep



Thalamus

During wakeful periods, the thalamus transmits information to the cortex, but during sleep it becomes rhythmic, generating spindle oscillations, selectively preventing signals from passing.

Hypothalamus

The hypothalamus makes connections with areas of the brain involved in arousal and wakefulness. During sleep, it shuts down their activity.

Pineal gland

This small gland is linked to the retina via the hypothalamus. When it gets dark, the gland releases the hormone melatonin, helping to synchronise the body with the environment.

Suprachiasmatic nucleus

The SCN is the biological clock. It contains just 50,000 neurons and is connected directly to the eyes. When it is light, it releases a powerful 'alert' signal.

Cerebral cortex

This is involved in the highest functions of the human brain. Much of it is deactivated during sleep, but during dreaming, parts of the cortex are even more active than when we are awake.

Stage 1

The first stage of sleep is the transition period. It is very light and lasts just a few minutes. As the brain shuts down, there can be some twitching as the muscles relax.

Stage 2

As people enter the second stage of sleep, their breathing and heart rate slow down and their body temperature drops. Around half of sleep time is spent in stage-2 sleep.

Stage 3

The third stage of sleep is described as 'deep sleep' and is characterised by the presence of a slow delta-wave pattern, representing the underlying activity of the brain stem.

Stage 4

We spend about ten per cent of the night in this deep sleep stage. Breathing is rhythmic and there is little muscle movement. Blood pressure drops and growth and repair process can begin.

Stage 5

Up to about five times a night, we enter rapid eye movement (REM) sleep. The brain returns to normal levels, but we remain unconscious and have dreams of five to 30 minutes each.

The developing brain

Baby

In order to fit through the birth canal, human babies must be born well before their brains have finished developing, so their brains grow rapidly in their first years. Experiences prompt the development of new connections between nerves, and by the time a baby is two years old, it has 1.5 times as many synapses as an adult.

Infant

Support cells, known as glia, provide protection, insulation and nutrition for the brain's nerve cells. Throughout childhood, they continue to migrate and grow. During the first two to three years of a child's life, the insulating white matter of the still-developing brain begins to form.

Child

By the age of ten or 11, the rapid development of new connections in the brain has ended and a period of trimming and pruning begins. Instead of creating extra pathways, the brain focuses in on the most important, strengthening and insulating those that are used more often and losing ones that are no longer valuable.

Making memories

The human brain has an amazing capacity for retaining information

Sensory memory

The body is constantly bombarded by sensory signals and most incoming sensory information is retained for less than a second before it is forgotten.

Transfer

The hippocampus integrates incoming sensory information, collecting it together as a single experience. It works together with the cortex to prioritise which information to store and which to forget.

Short-term memory

Without concentrating too hard, short-term memory can hold around seven items for 20 to 30 seconds. Collecting information into discrete chunks, like splitting a phone number up into sections, can help the brain retain more.

Implicit memory

These types of memories do not require conscious recall and are often based on motor skills. By repeating tasks, like riding a bike or playing the piano, pathways become automatic.

Explicit memory

Explicit memories are accessed consciously. They can be stored as episodes, linked to a specific event or place, or stored by category as more abstract knowledge.

Recall

Human memory is associative; it works by linking pieces of information together. Memories are not stored as individual entities, but reconstructed using several different parts of the brain.

Neuron changes

If a synapse is used repeatedly, it becomes increasingly sensitive to stimulation, producing more receptors and strengthening the connection.

Acoustic encoding

Short-term memory tends to be based on sound, also known as echoic memory. When remembering a phone number, it often helps to rehearse it vocally in your head.

Recognition

The brain is very good at making associations, and incoming information is compared to stored data, allowing us to quickly recall things we already know or have experienced before.

Association

Memories are rarely stored in isolation and one pathway is linked to others. Recognition and recall can both trigger other related memories.

Consolidation

Once the trace of a memory is formed, the pathway can be consolidated with use. The more often a synapse is used, the stronger it becomes.

Long-term memory

The hippocampus is essential for the transfer of memories from short to long term storage. Some of this memory consolidation happens in dreaming as the brain rehearses the day's activities.

Semantic encoding

Instead of being linked to an audio memory, long-term memories tend to be stored more abstractly, by concept. Other memories are stored as sensory echoes, allowing entire experiences to be remembered and reconstructed.

Teenager

Trimming and adjusting the brain starts at the back and works forward, continuing into the teenage years. The prefrontal cortex, involved in planning, judgement and emotional control, is the last to be finished. Research also suggests that adolescents' body clocks are wired differently, so they naturally go to bed and wake up later.

Adult

Most growth and remodelling is complete by our early 20s, but new connections continue to form in the adult brain, albeit at a much slower rate than in children. Staying active and providing the brain with engagement and stimulation strengthens existing connections, and new pathways continue to form as we learn.

Old age

Damage to the brain cannot easily be repaired, so as it ages, signs of wear start to appear. Connections are lost as nerve cells wither, or as debris builds up between synapses, and gradually mental function can decline, leading to age-related illnesses like Alzheimer's disease and Parkinson's.

is going on inside the human brain, rebuilding the entire structure using this method will still take decades. The alternative is to simulate the brain, taking what we already know and using it as a scaffold to build the parts we have yet to study. By going back and testing the model brain against the real data, scientists can check that their simulation is working as it should.

Japan's K Computer is one of the fastest and most powerful in the world, and in 2014, 83,000 of its processors were combined in order to simulate one per cent of one second of human brain activity. This was a huge achievement, but it took the machine 40 minutes and barely represented a fraction of the power of the human brain.

The problem is that most modern computers are built on architecture completely different to the human brain. The brain is made up of processing cores, capable of specialising to perform highly specific tasks. They are less precise, but have much more flexibility, and most importantly, the capacity to learn. Memories are not stored in one particular place, and are instead distributed across the network. In contrast, modern computers use programs in order to decide what to do, and they store elements in a hierarchical memory.

In 2013, the European Commission funded the Human Brain Project with a grant of €1 billion (£800 million/$1.3 billion) in order to accomplish just that. This ambitious, ten-year endeavour aims to develop cutting-edge computational tools to assist in the understanding of brain function, bringing together the fragments from different disciplines and providing an unprecedented map of human brain activity. The Human Brain Project hopes to use this information to build a supercomputer capable of simulating the network that makes up the human brain. They estimate that it would take one laptop to simulate the activity of one neuron and are working closely with IBM to develop powerful neuromorphic supercomputers.

Neuromorphic chips are computer chips modelled on the architecture of the human brain. IBM released a chip modelled on the human brain in 2014. Known as the SyNAPSE chip, it has one million 'neurons' connected by 256 million 'synapses'. They are arranged into 4,096 'synaptic cores', which function in parallel with one another, just like the processing cores in the brain. Just like the brain, they operate on demand and can compensate if one core happens to fail.

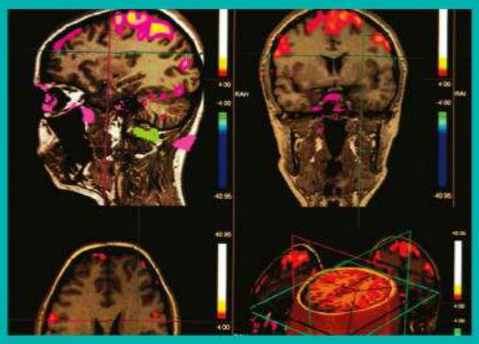
By feeding these computers with inputs that mimic biological signals, scientists can then

Imaging the brain

Take a look at the most common techniques used to study the living brain

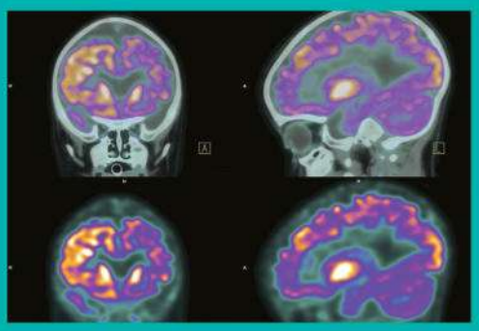
CT

Computed tomography (CT) scans use X-rays to build a three-dimensional image of the brain. The radiation travels at different speeds through different tissues, allowing a density map to be produced. It provides purely structural information and is useful for identifying tumours.



fMRI

Functional magnetic resonance imaging detects the amount of oxygen present in the blood, allowing brain activity to be mapped. When regions of the brain become more active, their demand for blood rises and they light up on the image. It captures a picture of the activity of the entire brain every two seconds.



PET

Positron emission tomography uses safe radioactive isotopes to measure brain activity. By labelling oxygen or sugar with radioactive tags, blood flow in the brain can be monitored. The tags emit low-energy radiation and as blood is diverted to active regions of the brain, the emissions pinpoint the locations.

EEG

Electroencephalograms take advantage of the electrical signals produced by nerves to produce a map of brain function. Electrodes placed on the scalp are able to detect the patterns of nerve activity beneath the surface. This technique comes in particularly handy for sleep studies.

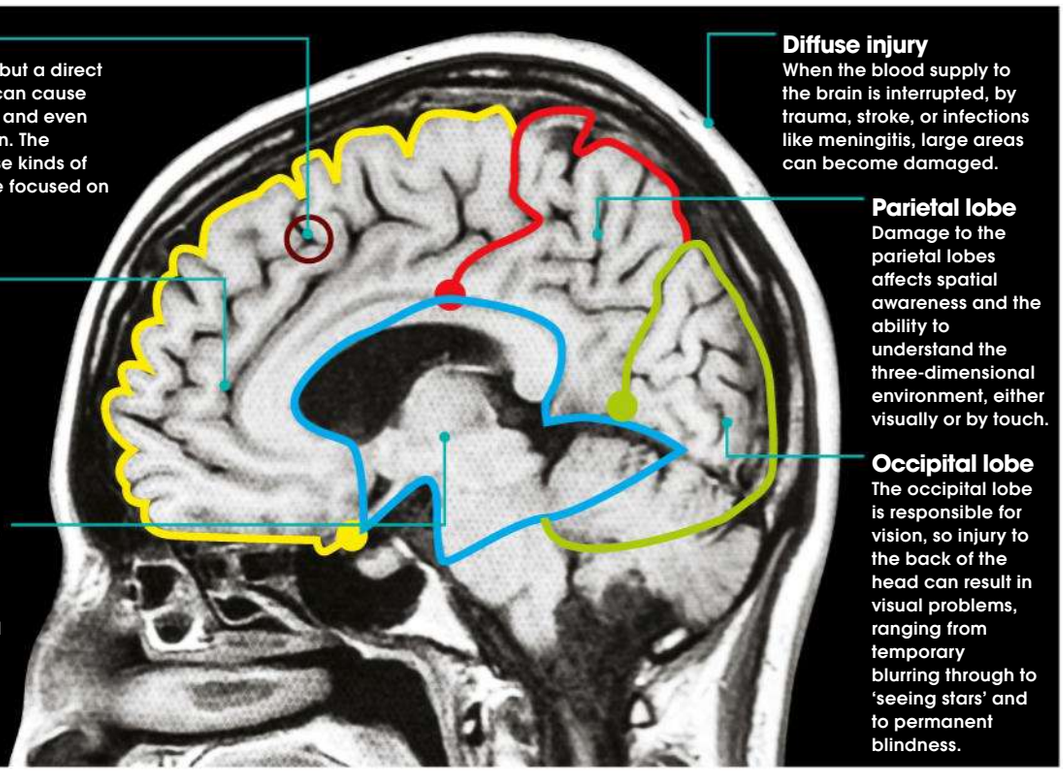
Brain damage

Different injuries affect the brain in different ways

Severe
If the injury is severe, the patient is no longer able to respond to sensory stimulation. Their eyes remain closed and there is no response at all to verbal cues.

Moderate
When brain injury is more severe, verbal communication starts to break down and patients no longer respond normally to pain.

Mild
With mild brain injury, patients may be confused, but they remain aware, conscious and conversational.



"The brain is made up of processing cores, capable of specialising to perform highly specific tasks"

examine the electrical activity and can see where information is being processed and stored. The project is a collaboration between over 100 institutions in 24 countries.

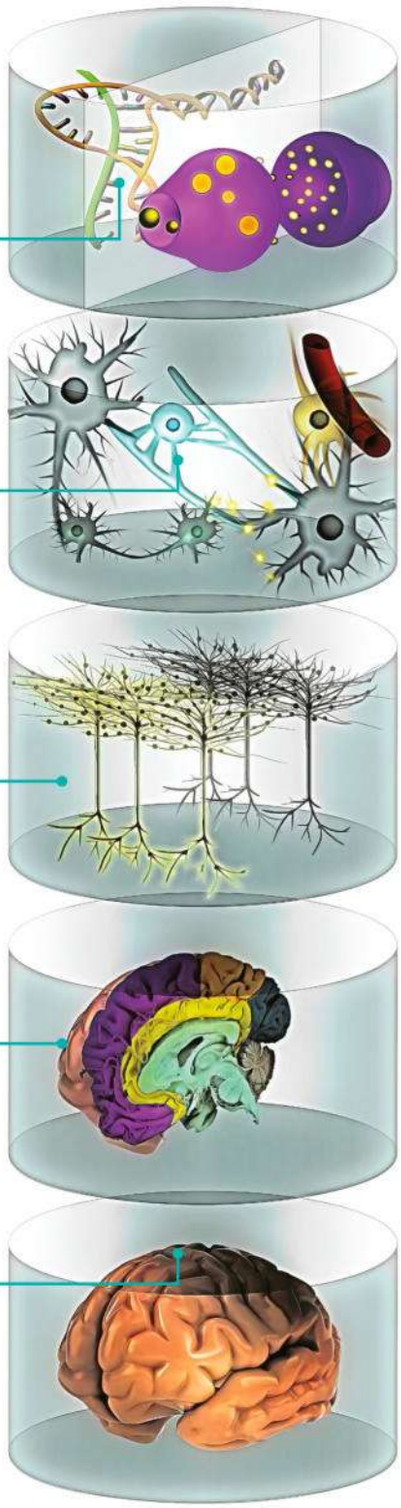
New technology is the key to modelling a structure as complex as the human brain, and other international efforts are also in place to provide new technology. In 2013, US President Barack Obama announced the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative. The NIH (National Institutes of Health) allocated £24 million ($40 million) in 2014 to develop new technologies to find the best way to understand the brain. In order to break the brain down and rebuild it accurately, the project combined silicon-based techniques and advancements in stem-cell biology, brain imaging and medical drug development.

Cutting-edge neuroscience

The human brain is one of the most complex structures in the known universe and understanding how it works is an enormous scientific undertaking. Modern neuroscience brings together experts from a huge array of fields and scientists are finally beginning to untangle the many mysteries of the human brain

Building a brain

Large-scale projects aim to simulate the human brain at every level



DNA and neurotransmitters

At the molecular level, scientists are able to manipulate the 3D structures of proteins using computer programmes, and to model the effects that changes might have. Such techniques are hugely useful in drug design.

Nerves and support cells

In order to gain a proper understanding of how the brain functions, many scientists advocate a bottom-up approach. By creating digital neurons that are based on the underlying rules and principles of biology, it is hoped that the complex network of the brain can be simulated.

Neural pathways

Some projects aim to map all of the connections in the human brain, generating a 3D representation of the intricate wiring. Others aim to simulate the process, allowing the computer to make its own connections based on biological rules.

Lobes and structures

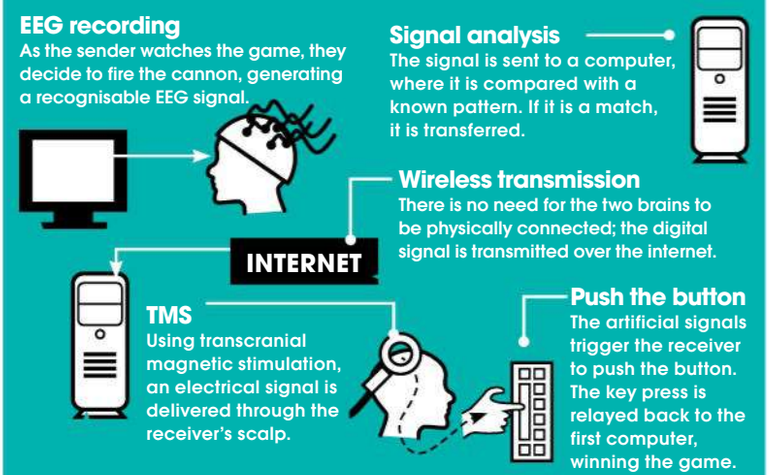
Simulations will allow information about different structures in the brain to be integrated, enabling scientists to more closely examine the interactions between different areas, or even to remove one region and study it in isolation.

Whole brain

In 2013, the K Computer in Japan carried out one second of simulated human brain activity. With 705,024 processor cores, it took the machine 40 minutes to simulate a network just one per cent of the size of the human brain. Advanced processors due in the next ten years will increase this capability significantly.

How mind control works

Simple equipment and complex computer programming allow our thoughts to be transmitted over the internet



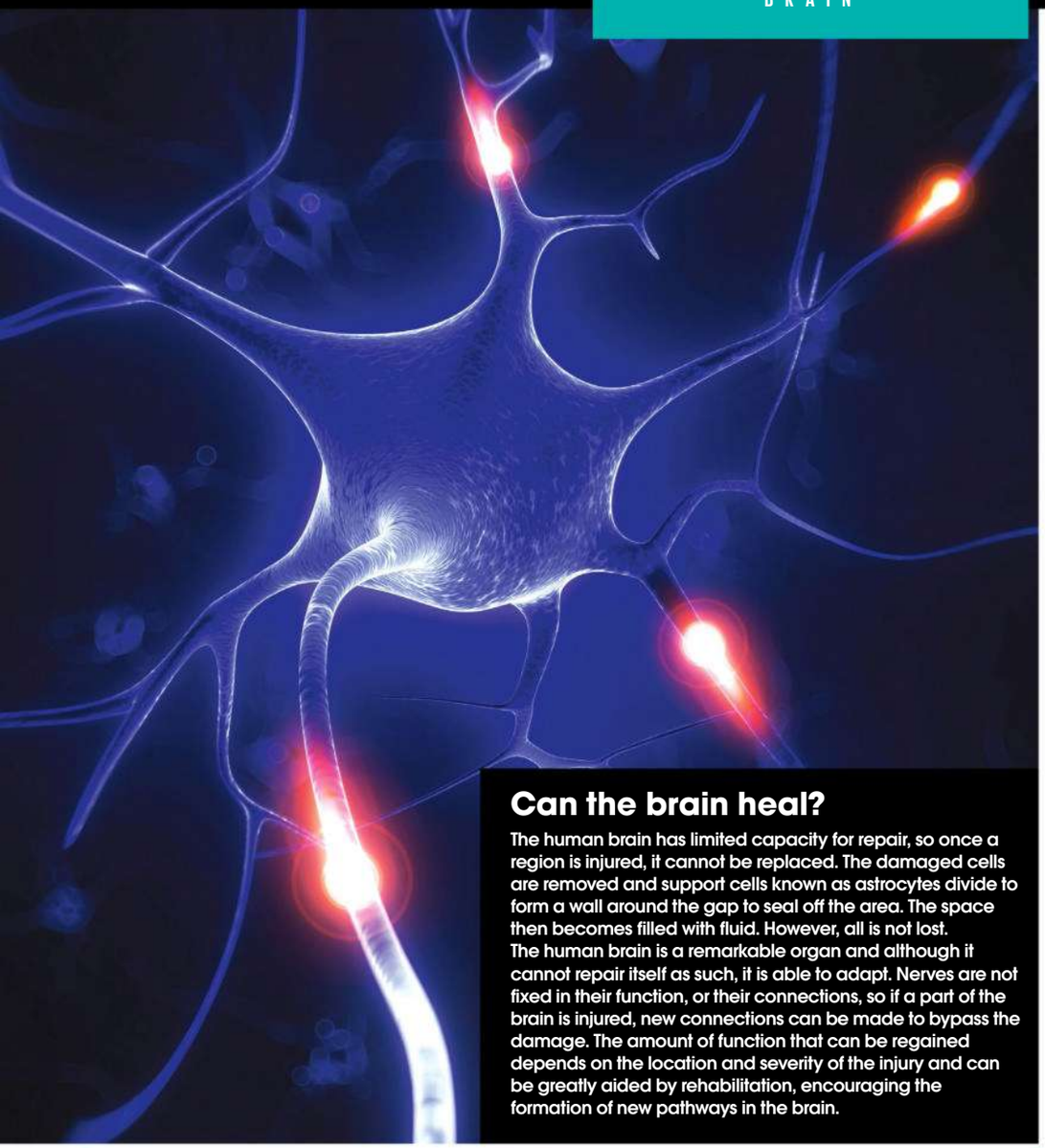
Mind control

In a groundbreaking experiment in 2013, researchers at the University of Washington successfully linked two human brains together and proved their principle with a video game.

The city is under attack by pirates, where player one, the sender, must intercept their rockets. They can see the screen and are armed with a cannon, but they do not have a keyboard and cannot press 'fire'. Player two, the receiver, is sitting in another room; he cannot see the game, but he does have a keyboard. Player one thinks about firing the cannon, and fractions of a second later, player two pushes the button, saving the city and winning the game.

Player one was wired up to an electroencephalogram (EEG) and his brain activity was being monitored. When he was thinking about pressing the button, there was a characteristic signal in the 'mu band' of the EEG, triggering the program to send a wireless signal to player two.

Player two was wearing a specially designed coil on his scalp that generated a magnetic field, positioned over the part of the brain that controls contraction in the right hand. The signal from player one was converted into magnetic stimulation, which in turn triggered electrical activity in the brain, causing player two to involuntarily fire the cannon.



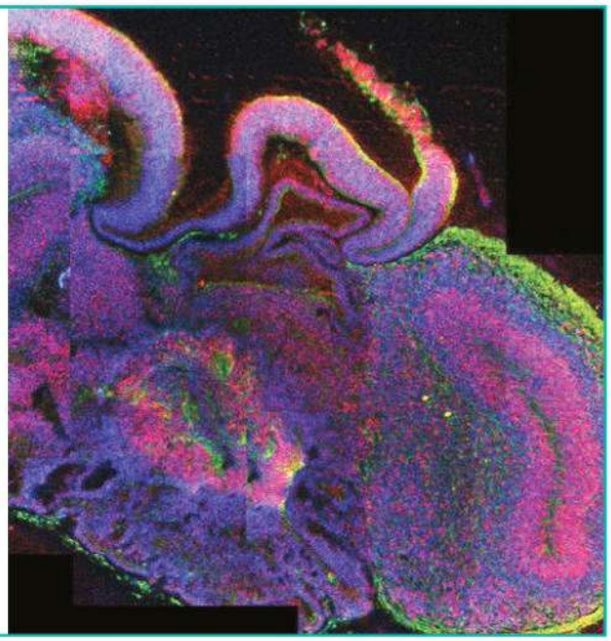
Can the brain heal?

The human brain has limited capacity for repair, so once a region is injured, it cannot be replaced. The damaged cells are removed and support cells known as astrocytes divide to form a wall around the gap to seal off the area. The space then becomes filled with fluid. However, all is not lost.
The human brain is a remarkable organ and although it cannot repair itself as such, it is able to adapt. Nerves are not fixed in their function, or their connections, so if a part of the brain is injured, new connections can be made to bypass the damage. The amount of function that can be regained depends on the location and severity of the injury and can be greatly aided by rehabilitation, encouraging the formation of new pathways in the brain.

Growing a brain

In 2013, scientists at the Austrian Academy of Sciences achieved something incredible; they grew part of a human brain in a Petri dish. Using a combination of embryonic stem cells and stem cells taken from adult skin, the team recreated the neuroectoderm, the embryonic structure that goes on to form the brain and the spinal cord.

The cells were put in three-dimensional scaffolds to give them something to grow around, and then given nutrients and oxygen and allowed to develop. Amazingly, the structures organised themselves into something resembling the brain of a nine-week-old foetus. Some contained the pigmented cells of a retina, others developed a cortex and some even had a hippocampus. These mini-brains are about the size of a pea, and incapable of conscious thought, but could provide a valuable tool for researchers.



"Researchers are using electricity to selectively erase memories"

The practical applications of this future technology are incredible, but we are already able to interface with the brain in more ways than ever before. Light-sensitive retinal implants can restore sight to the blind by sending electrical signals to the optic nerve, while auditory brainstem implants communicate sound signals directly to the brain in patients who are profoundly deaf.

However, one of the most incredible technological developments of all is the BrainGate system, first revealed in 2006 and now undergoing clinical trials. The technology uses a sensor implanted on the motor cortex of the brain to pick up electrical signals generated when the patient thinks about moving. These signals are then decoded by a computer program and sent to a prosthetic limb. By carefully training the program to recognise specific signals, patients are able to move their bionic hands using just the power of their brains.

Taking electrical brain interfaces one step further, at the University of California, San Diego, researchers are using electricity to selectively erase memories. They have shown that by using particular frequencies of electrical pulses they can produce changes in the nerve cells in the brains of rats, making them forget traumatising experiences in their past.

As we continue to learn more about the connections in the brain, the possibilities for interacting with it will only continue to increase. The field of neuroscience is advancing faster than ever before, and huge international collaborations, like the Human Brain Project and the BRAIN initiative, are bringing mountains of research data together, creating resources that will revolutionise the field of neuroscience.

The puzzle of the human brain has been vexing scientists, doctors, and philosophers for thousands of years and understanding how it works is perhaps the most challenging problem in the history of science. However, with a combination of powerful new technology and international collaboration, the complexity of this mass of neurons is starting to unravel. Very soon, we might even be able to rebuild a functioning digital brain from the bottom up.

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Science of vision

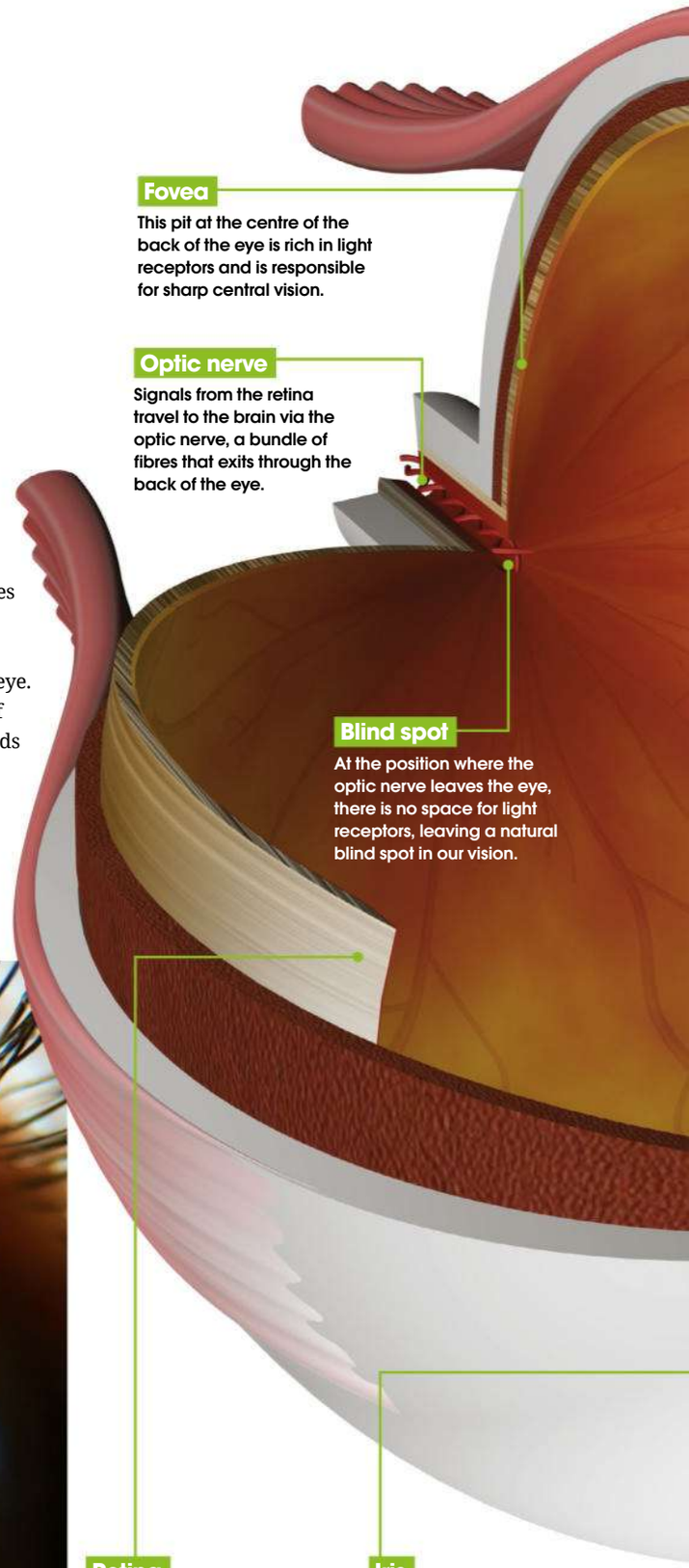
Uncovering one of the most complex constructs in the natural world

The structure of the human eye is so complex that it's difficult to believe that it's not the product of intelligent design but by looking at the eyes of other animals, scientists have shown that it evolved very gradually from a simple light-dark sensor over the course of around 100 million years.

The eye functions in a very similar way to a camera, with an opening through which the light enters, a lens for focusing and a light-sensitive membrane at the back.

The amount of light that enters the eye is controlled by the circular and radial muscles in the iris, which contract and relax to alter the size of the pupil. The light first passes through a tough protective sheet called the cornea, and then moves into the lens. This adjustable structure bends the light, focusing it down to a point on the retina, at the back of the eye.

The retina is covered in millions of light-sensitive receptors known as rods and cones. Each receptor contains pigment molecules, which change shape when they are hit by light, triggering an electrical message that travels to the brain via the optic nerve.



Ciliary body

This tissue surrounds the lens and contains the muscles responsible for changing its shape.

Sclera

A tough white membrane known as the sclera helps to maintain the eye's spherical shape.

Lens

The lens is responsible for focusing the light, and can change shape to accommodate objects near and far from the eye.

Pupil

The pupil is a hole that allows light to reach the back of the eye.

Cornea

The pupil and iris are covered in a tough, transparent membrane, which provides protection and contributes to focusing the light.

Vision problems

The most common problems with our eyesight

Farsightedness (hyperopia)

If the eye is too short, the cornea is too flat, or if the lens sits too far back, incoming light is focused behind the retina, making nearby objects appear blurry, particularly in the dark.

Nearsightedness (myopia)

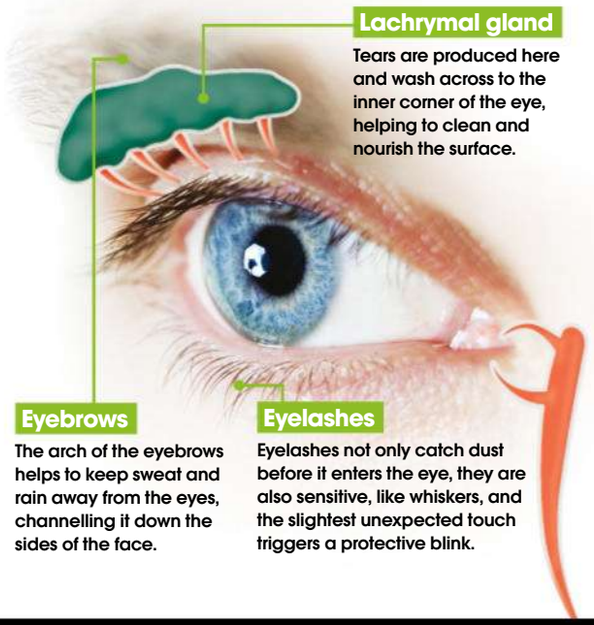
If the eye is too long, or the cornea and lens are too curved, the light is focused before it hits the back of the eye, and then starts to defocus again as it reaches the retina, making distant objects difficult to see.

Colour-blindness

This rare condition is often linked to a gene on the X-chromosome and occurs more commonly in men than in women. A defect in the cone cells of the eye reduces the number of colours that can be detected.

Protection

The eyes are shielded by several layers of protection. They are almost completely encased in bone at the back and insulated from shock by layers of muscle and connective tissue. The front is kept moist with tears and constantly wiped by the eyelids, while the hairs of the eyebrows and eyelashes catch any debris that might fall in.



Lachrymal gland

Tears are produced here and wash across to the inner corner of the eye, helping to clean and nourish the surface.

Eyebrows

The arch of the eyebrows helps to keep sweat and rain away from the eyes, channelling it down the sides of the face.

Eyelashes

Eyelashes not only catch dust before it enters the eye, they are also sensitive, like whiskers, and the slightest unexpected touch triggers a protective blink.

Colour vision

Why humans see the world in so many colours

Open your eyes, and you are met with an array of different colours, but amazingly you can only detect three different wavelengths of light, corresponding to green, blue, and red. Combining these three signals in the brain creates millions of different shades.

Each eye has between 6 and 7 million cone cells, containing one of three colour-sensitive proteins known as opsins. When photons of light hit the opsins, they change shape, triggering a cascade that produces electrical signals, which in turn transmit the messages to the brain. Well over half of our cone cells respond to red light, around a third to green light, and just two per cent to blue light, giving us vision focused around the yellow-green region of the spectrum.

The vast majority of the cone cells in the human eye are located in the fovea, a spot in the centre of the retina, measuring fractions of a millimetre across. Light is focused on this point, providing a crisp, full-colour image at the centre of our vision. The remainder of the retina is dominated by 120 million rod cells, which detect light, but not colour.

We're so used to seeing the world in red, green and blue that it might seem strange that most other animals cannot, but three-coloured vision is relatively unusual. Some species of fish, reptiles and birds have four-colour vision, able to see red, green, blue and ultraviolet or infrared light, but during mammalian evolution, two of the four cone types were lost, leaving most modern mammals with dichromatic vision – seeing in shades of just yellow and blue.

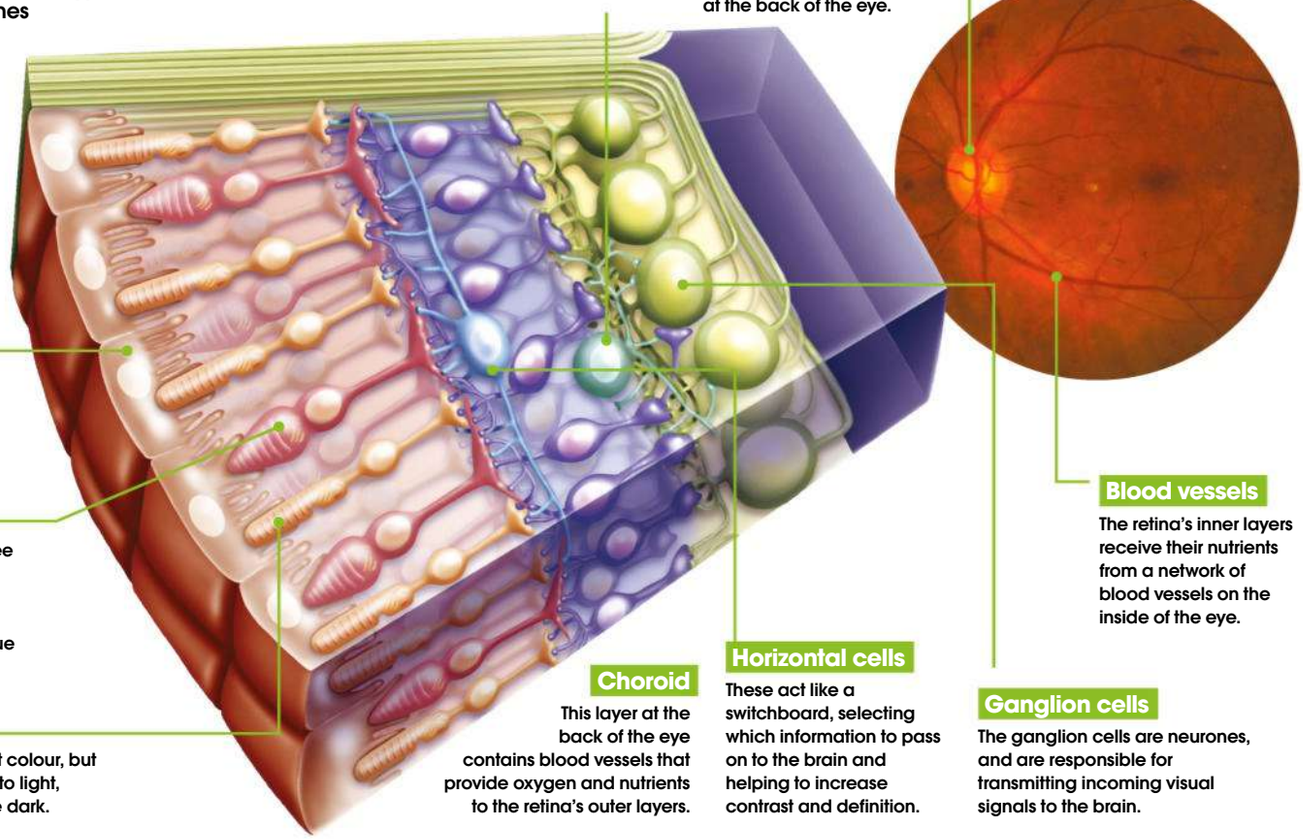
This was not a problem for many early mammals, because they were largely nocturnal, and lived underground, where there was little need for colour vision. However, when primates started moving into the trees, a gene duplication gave some species the ability to see red, providing an evolutionary advantage in picking out ripe red fruit against the green leaves.

Even today, not all primates can see in three colours; some have dichromatic vision, and many nocturnal monkeys only see in black and white. It is all down to their environment.

Night monkeys have large eyes that enhance their nocturnal vision

Light and colour

As light hits the back of the eye, it interacts with two different types of cell; rods and cones



How we see

Look around you – do you know what you're seeing with?

The back of the eye is covered in a layer of light-sensitive cells. When photons of light hit the pigments inside the cells, it triggers a cascade of signals that are transmitted to the brain.

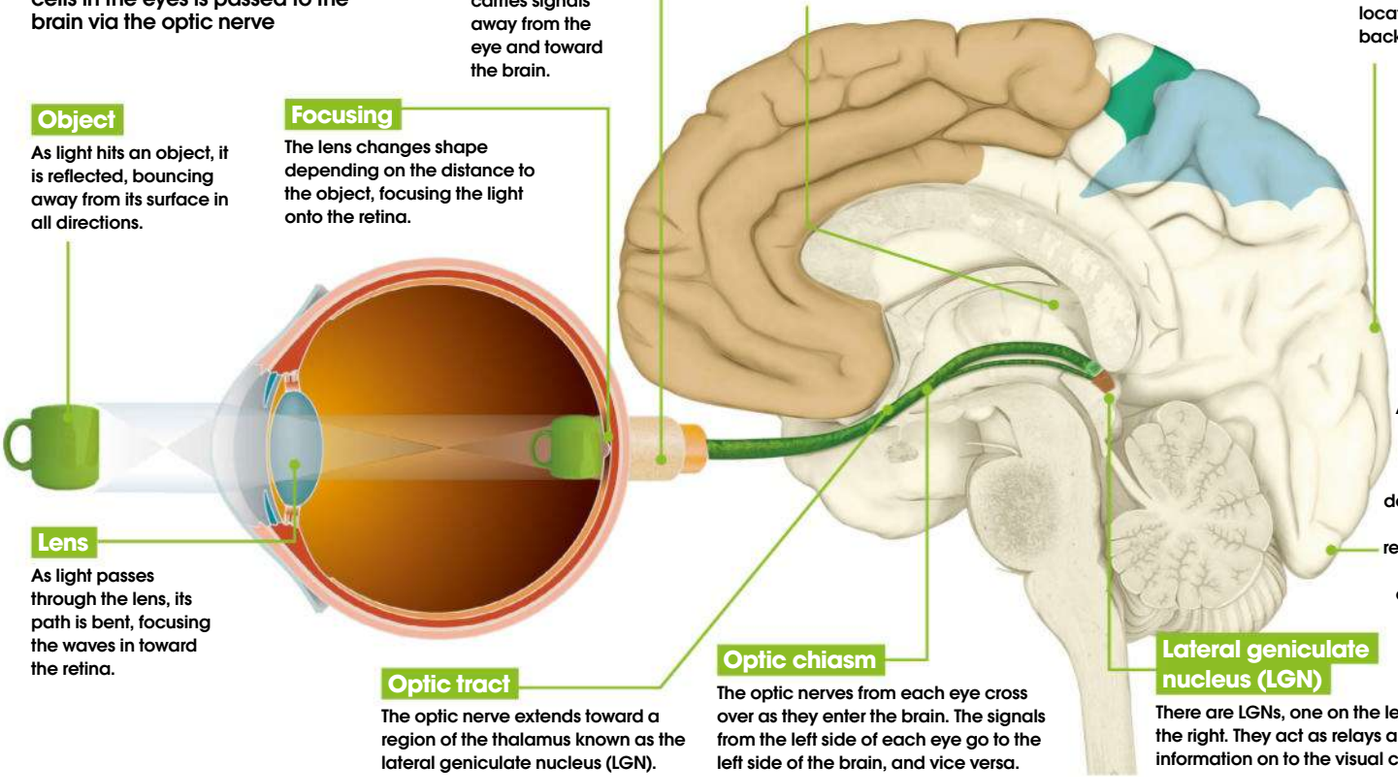
First, they move through interneurones and then to neurones known as ganglion cells. These cells are cross-linked, able to compare adjacent signals, filtering out some of the information. This helps to improve contrast and definition. The neurones travel across the back surface toward the optic nerve, which then relays the information into the brain.

As the two optic nerves enter the brain, they cross over, coming together at the optic chiasm. Here, signals from the left side of both eyes are diverted to the left side of the brain, and vice versa, allowing the images from both eyes to be combined and compared.

The signals enter the brain via the thalamus, where the information separates into two parts, one containing colour and detail, and the other movement and contrast. The messages then move into the visual cortex. The cortex is laid out so that it mirrors the back of the retina, allowing a detailed image to be reconstructed.

Optic nerve

Information from the light-sensitive cells in the eyes is passed to the brain via the optic nerve



Quick-fire questions

Why do we see in black and white at night?
The colour-sensitive cone cells in the eye function like slow camera film – they produce highly detailed images, but require lots of light to work. In contrast, light-sensitive rod cells are like fast film. They respond to low levels of light, but cannot detect colour, producing a grainy, black-and-white image.

Why does our eyesight get worse as we get older?
As the eye ages, the lens becomes less flexible, making it increasingly difficult to focus on nearby objects. Luckily, this is easily corrected with glasses. Cloudy areas, known as cataracts, can also start to appear within the lens, making vision appear blurred or misty, but this can often be fixed with simple surgery.

Why do our eyes jump instead of moving around smoothly?
Movement of the eye is controlled by the brainstem. Our vision would be blurry if our eyes moved smoothly, so they jump in steps known as saccades. The brain stitches the images together, like the frames in a film, producing the illusion of continuous movement.

Why do some animals have their eyes on the sides of their head?
Forward-facing eyes are incredibly useful for primates, who need to be able to accurately judge depth when jumping between trees, for example, and for predators who need to pinpoint their prey. In contrast, prey animals need to be able to watch for danger, and often sacrifice binocular vision for a more rounded view of their environment.

How corrective lenses work

An important tool for sight deficiencies, corrective lenses restore 20/20 vision and reduce eye strain

In optics, a lens is a transparent substance (usually glass) that is used to form an image of an object by focusing rays of light to a designated point. In eyeglasses, lenses are used to correct a wide variety of eye defects including myopia, hyperopia and astigmatism. This is achieved by shaping the lenses into various optical profiles, the most common of which is ophthalmic convex-concave. Here, both the front and back of the lens surface has a positive radius, resulting in a convergent front surface and divergent back surface. This difference creates the corrective power of the lens, so in order to treat hyperopia a convergent lens is used, where the front surface is stronger than the rear (narrowing the incoming light's focus); for myopia, the reverse is used, with the rear surface holding a greater magnitude (widening the light's focus point).

Modern corrective lenses can be formed with multiple spherical surfaces, granting them a highly complex profile. This allows bifocal and trifocal lenses to be produced, where different parts of the lens are shaped and hold powers suitable for various distances of focus.

Pinhole glasses

How do these lens-less glasses help correct vision?

Pinhole glasses – technically called stenopeic glasses – are eyeglasses that consist of two plastic opaque sheets filled with a series of pinhole-sized holes. These perforated sheets replace the lenses of the glasses and, when worn, reduce the amount of light entering each eye to a series of narrow beams. This reduction in light reduces the circle of confusion (an optical blur spot) on the eyes' retina, while also increasing depth of field. Unlike lens-based glasses though, pinhole glasses produce an image without generating a pincushion distortion (an effect where image magnification increases with the distance from the optical axis, as seen in binoculars). In essence, stenopeic glasses work on the same principle of pinhole cameras, producing a sharper image but at the expense of brightness.

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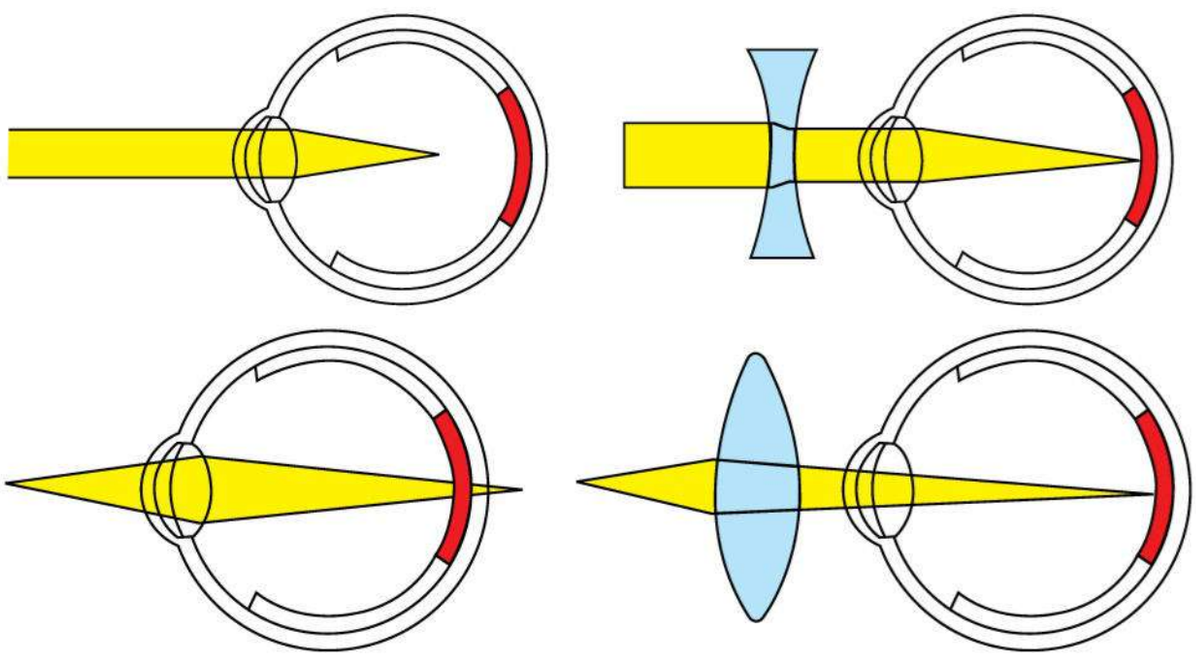
How lenses can be used to treat myopia and hyperopia



Myopia (short-sightedness)

A refractive defect of the eye in which collimated (parallel) light is forced to produce images in front of the retina instead of upon it, myopia is treated through the use of a concave lens. This causes incoming light to enter the cornea at a different angle and diverge on the retina.

Hyperopia (long-sightedness)

A vision defect usually caused by the eyeball being too short or its cornea not being rounded enough during development, hyperopia causes difficulty in focusing on near objects. It is treated by the application of a concave lens, which adjusts the focus of incoming light so it accurately displays on the retina.

How the eye focuses

The tiny rings of muscle that make your vision sharp

Cameras and human eyes both focus light using a lens. This structure bends the incoming wavelengths so that they hit the right spot on a photographic plate, or on the back of the eye. A camera lens is made from solid glass, and focuses on near and distant objects by physically moving closer or further away. A biological lens is actually squishy, and it focuses by physically changing shape.

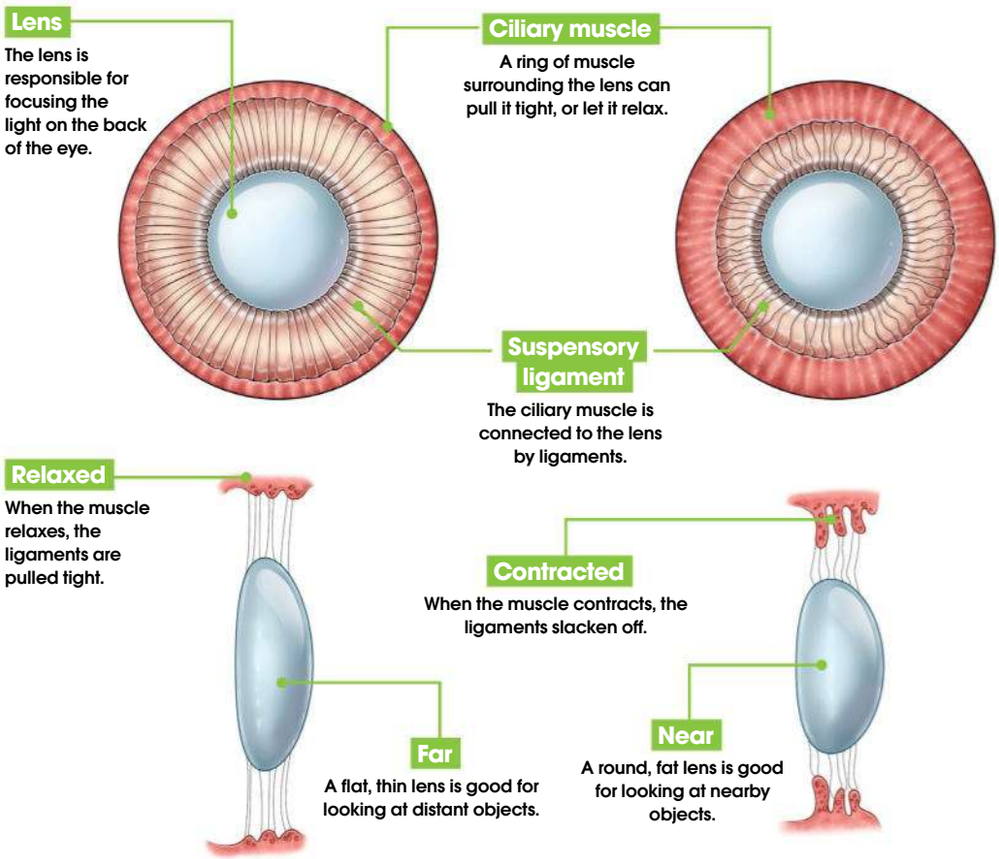
In the eye, this process is known as 'accommodation', and is controlled by a ring of smooth muscle called the ciliary muscle. This is attached to the lens by fibres known as suspensory ligaments. When the muscle is relaxed, the ligaments pull tight, stretching the lens until it is flat and thin. This is perfect for looking at objects in the distance.

When the ciliary muscle contracts, the ligaments loosen, allowing the lens to become fat and round. This is better for looking at objects that are nearby. The coloured part of the eye (called the iris) controls the size of the pupil and ensures the right amount of light gets through the lens.

Beneath the iris, muscles are working hard to adjust the lens

Accommodation explained

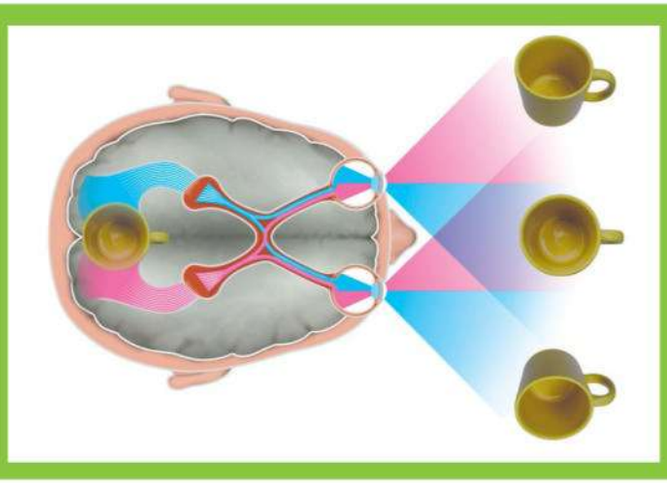
How the lens changes its shape to focus on near and distant objects



Seeing in three dimensions

Each eye sees a slightly different image, allowing the brain to perceive depth

Our eyes are only able to produce two-dimensional images, but with some clever internal processing, the brain is able to build these flat pictures into a three-dimensional view. Our eyes are positioned about five centimetres (two inches) apart, so each sees the world from a slightly different angle. The brain then compares the two pictures, using the differences to create the illusion of depth.



Individual image

Due to the positioning of our eyes, when objects are closer than about 5.5m (18ft) away, each eye sees a slightly different angle.

Combined image

The incoming signals from both eyes are compared in the brain, and the subtle differences are used to create a three-dimensional image.

Try it for yourself

By holding your hand in front of your face and closing one eye at a time, it is easy to see the different 2D views perceived by each eye.

The retina

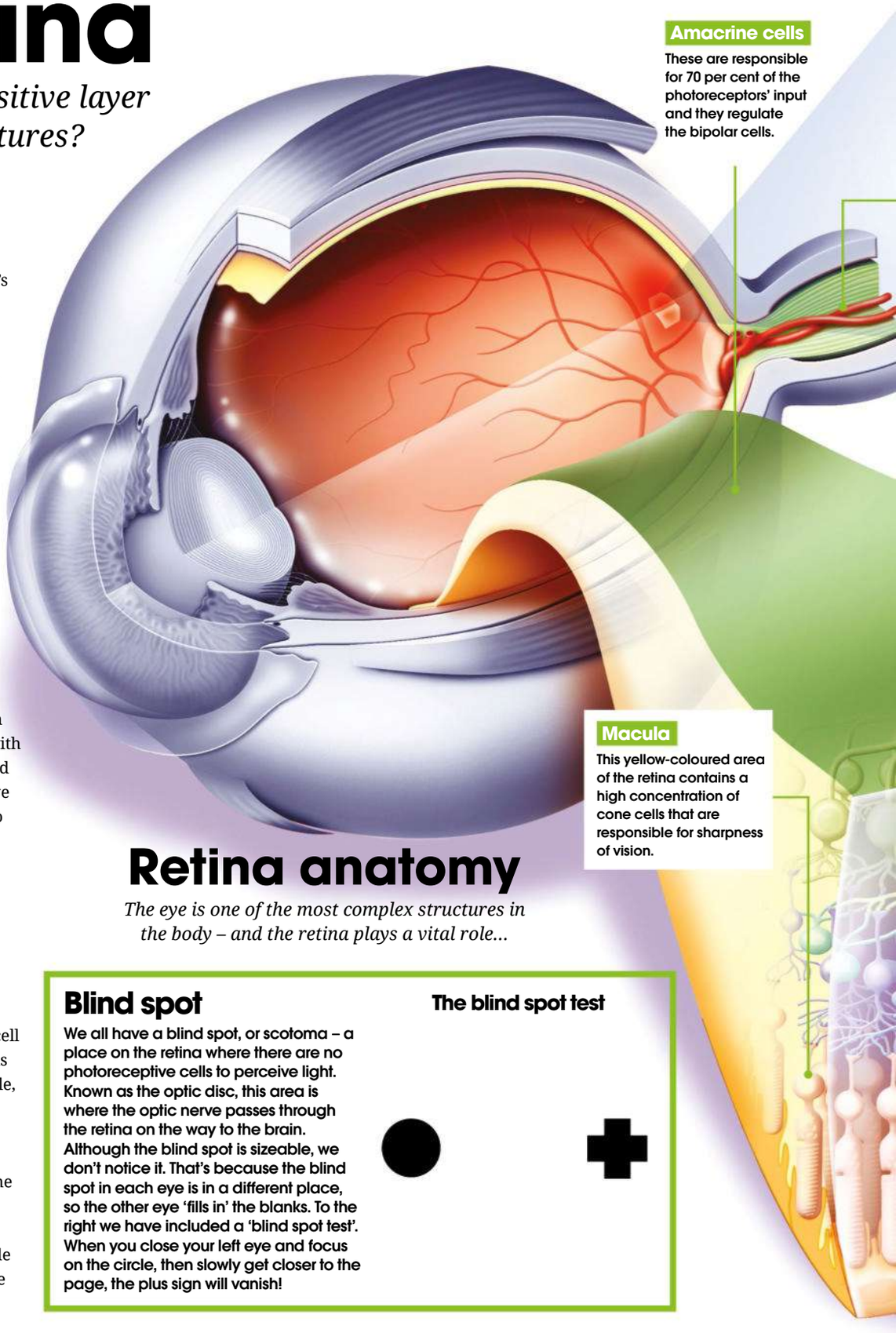
How does this photosensitive layer enable us to see pictures?

The retina is a special type of light-sensitive tissue located in the interior of the eye that's so analogous to brain tissue, it's considered a part of the central nervous system. If you consider our eyes to be cameras, then the retina is the film. However, the retina does much more than just send a 'picture' to the brain – it actually has to compress the image so that it can be conveyed via the optic nerve, because the photoreceptors in the retina can take in more information than the optic nerve can convey.

Although it looks like a single layer, the retina is actually very complex and comprises ten layers of nerve cells, all of which are connected by synapses. Within each of these layers are several different types of cells: the photoreceptors called rods and cones, photosensitive ganglion cells, bipolar cells and other cells that assist with regulating light input as well as processing and transmitting images. Rods and cones each have their own function. Rods are more sensitive to light and are responsible for night vision and peripheral vision; each one can respond to a single photon, or particle, of light. Cones, on the other hand, work in bright light and are responsible for seeing colour, fine detail and rapid movements.

Until the Nineties, it was thought that only rods and cones were involved in sight. Then researchers discovered a much rarer type of cell called photosensitive ganglion cells. These cells help regulate pupil size and the light/dark cycle, or circadian rhythms, that we function by.

Light reaches the rods and cones by first passing through transparent layers of nerve cells. When it reaches these photoreceptors, the light causes chemical changes in the rods and cones. The raw data is sent back through the layers of nerve cells, which process and encode the image before sending it via the optic nerve to the brain.



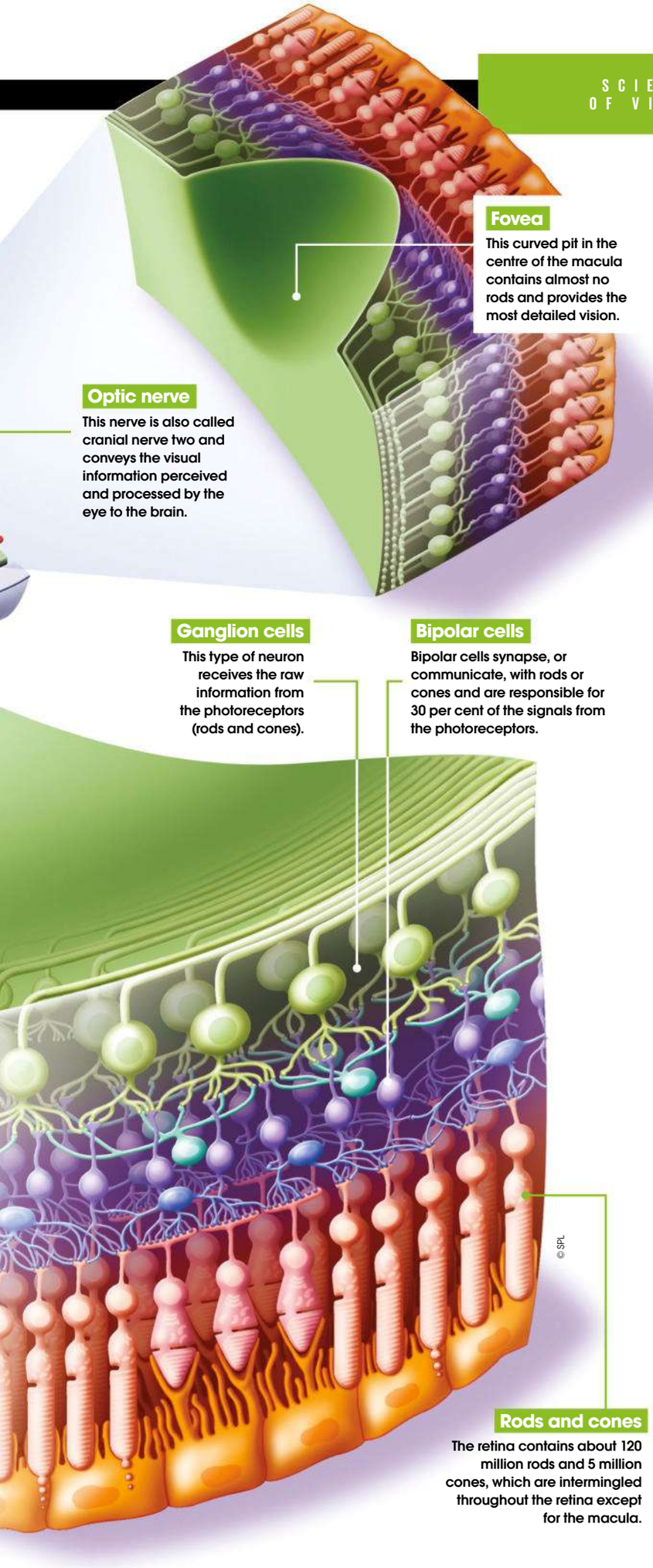
Retina anatomy

The eye is one of the most complex structures in the body – and the retina plays a vital role...

Blind spot

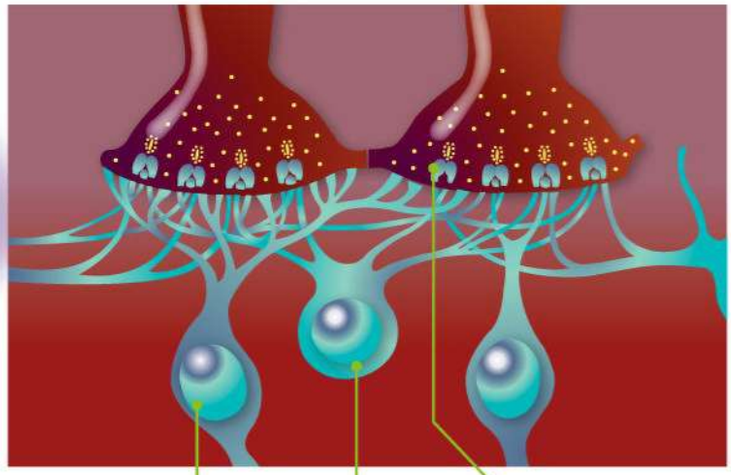
We all have a blind spot, or scotoma – a place on the retina where there are no photoreceptive cells to perceive light. Known as the optic disc, this area is where the optic nerve passes through the retina on the way to the brain. Although the blind spot is sizeable, we don't notice it. That's because the blind spot in each eye is in a different place, so the other eye 'fills in' the blanks. To the right we have included a 'blind spot test'. When you close your left eye and focus on the circle, then slowly get closer to the page, the plus sign will vanish!

The blind spot test



Synapses

Neurons work together to combine data from rod and cone cells into messages that travel to the brain



Orange and pink lines reveal the complex structure of retinal blood vessels coming through the optic disc

Retinal scan

Iris scanning is the more common form of biometrics when it comes to eyes, but did you know that our retinas also have special identifying characteristics? It all comes down to the complex network of blood vessels in the retina; even twins' retinas are different. When you look into a retinal scanner, a low-energy beam of infrared light is reflected by the capillaries. The resulting unique pattern is then stored as code within a database. Retinal scanners are fast and reliable, but the downside is that the scanners are expensive and the pattern can change over time with certain diseases or other eye problems.

© Danny Hope

How ears work

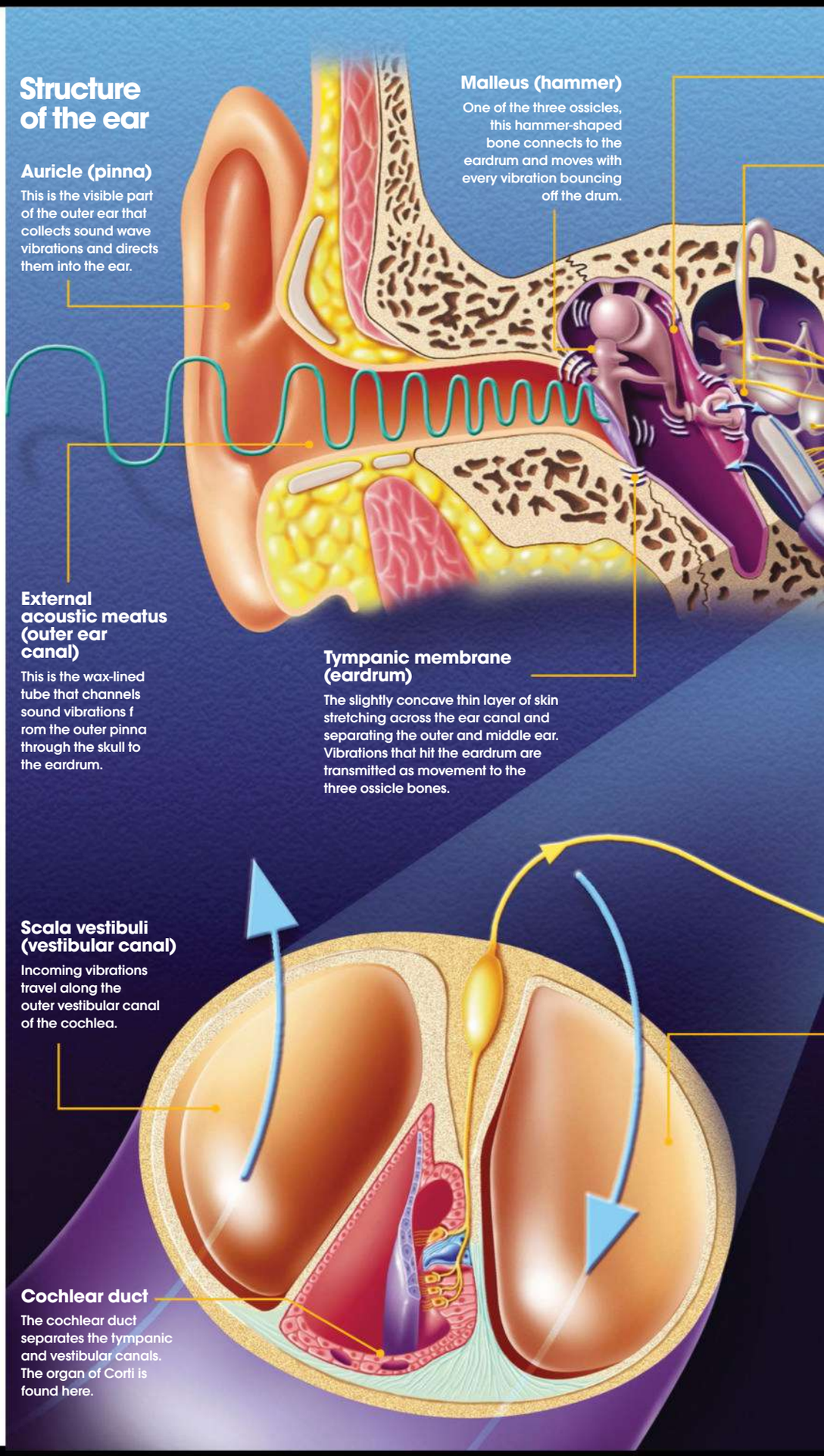
The human ear performs a range of functions, but how do they work?

Sound is all about movement. When someone speaks the air around them is disturbed, creating a sound wave of alternating high and low frequency which are detected by the ear and interpreted by the brain.

Consisting of air-filled cavities, labyrinthine fluid-filled channels and highly sensitive cells, the ear has external, middle and internal parts. The outer ear consists of a skin-covered flexible cartilage flap called the 'auricle', or 'pinna' which is shaped to gather sound waves and amplify them before they enter the ear for processing and transmission to the brain. When a sound wave enters the ear it hits the eardrum, or tympanic membrane, a sheet of tightly pulled tissue separating the outer and middle ear that vibrates as sound waves hit it.

Beyond the eardrum, in the air-filled cavity of the middle ear, are three tiny bones called the 'ossicles', the smallest bones in the human body. Sound vibrations hitting the eardrum pass to the first ossicle, the malleus (hammer). Next the waves proceed along the incus (anvil) and then on to the (stapes) stirrup. The stirrup presses against a thin layer of tissue called the 'oval window' and into the fluid-filled inner ear.

Here the vibrations enter the watery ducts of the cochlea and are channelled, as ripples, along its spiralling tubes. Running through the middle of the cochlea is the organ of Corti, lined with sensory hair cells that pick up on the vibrations and generate nerve impulses that are sent to the brain as electrical signals. The brain can interpret these signals as sounds.



Incus (anvil)

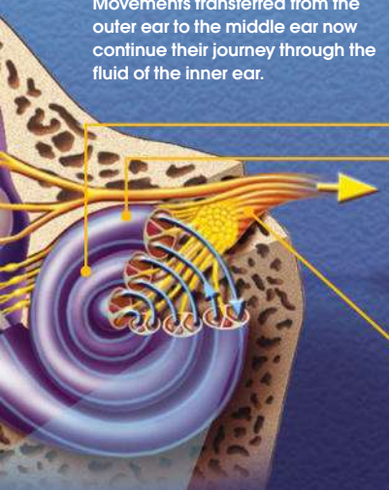
Connected to the hammer, the incus is the middle ossicle bone and is shaped like an anvil.

Stapes (stirrup)

The stirrup is the third ossicle bone. It attaches to the oval window at the base of the cochlea. Movements transferred from the outer ear to the middle ear now continue their journey through the fluid of the inner ear.

Cochlea

A bony snail-shaped structure, the cochlea receives vibrations from the ossicles and transforms them into electrical signals that are transmitted to the brain. There are three fluid-filled channels – the vestibular canal, the tympanic canal and the cochlea duct – within the spiral of the cochlea.

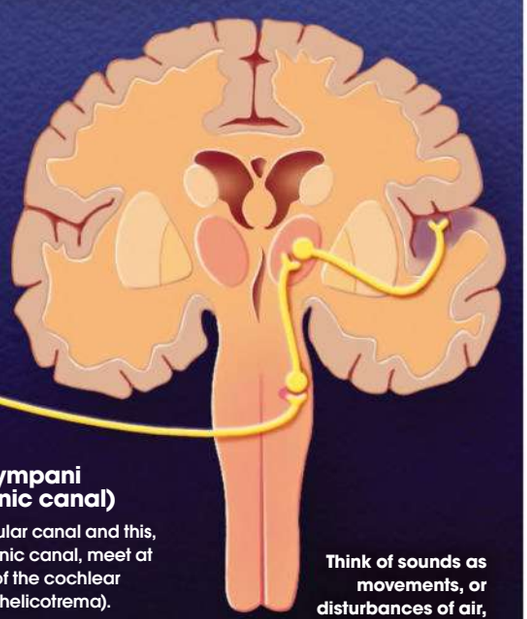


Organ of Corti

The organ of Corti contains rows of sensitive hair cells, the tips of which are embedded in the tectorial membrane. When the membrane vibrates, the hair receptors pass information through the cochlear nerve to the brain.

Cochlear nerve

Sends nerve impulses with information about sounds from the cochlea to the brain.



Scala tympani (tympanic canal)

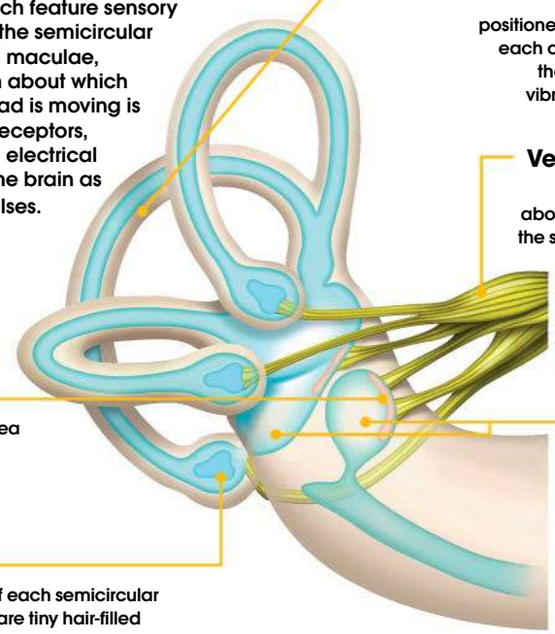
The vestibular canal and this, the tympanic canal, meet at the apex of the cochlear spiral (the helicotrema).

Think of sounds as movements, or disturbances of air, that create waves

© Science Photo Library

The vestibular system

Inside the inner ear are the vestibule and semicircular canals, which feature sensory cells. From the semicircular canals and maculae, information about which way the head is moving is passed to receptors, which send electrical signals to the brain as nerve impulses.



Semicircular canal

These three loops positioned at right angles to each other are full of fluid that transports sound vibrations to the crista.

Vestibular nerve

Sends information about equilibrium from the semicircular canals to the brain.

© DK Images

Macula

A sensory area covered in tiny hairs.

Vestibule

Inside the fluid-filled vestibules are two chambers (the utricle and saccule), both of which contain a structure called a macula, which is covered in sensory hair cells.

Crista

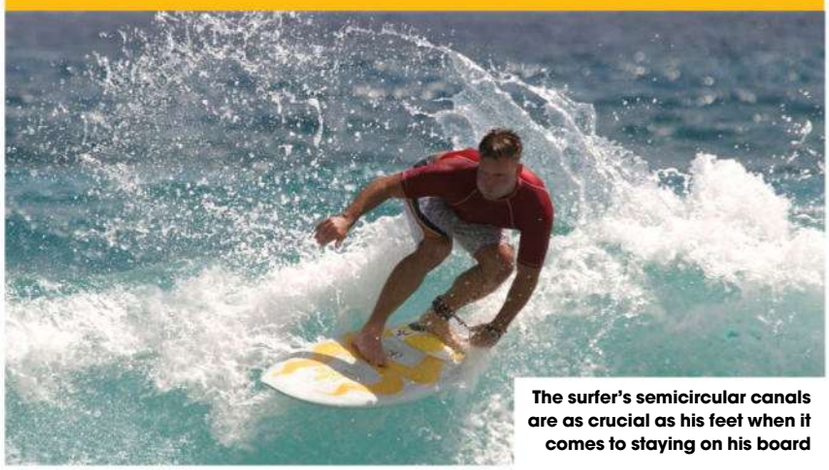
At the end of each semicircular canal there are tiny hair-filled sensory receptors called cristae.

A sense of balance

The vestibular system functions to give you a sense of which way your head is pointing in relation to gravity. It enables you to discern whether your head is upright or not, as well as helping you to maintain eye contact with stationary objects while your head is turning.

Also located within the inner ear, but less to do with sound and more concerned with the movement of your head, are the semicircular canals. Again filled with fluid, these looping ducts act like internal accelerometers that can actually detect acceleration (ie, movement of your head) in three different directions due to the positioning of the loops along different planes. Like the organ of Corti, the semicircular canals employ tiny hair cells to sense movement. The canals are connected to the auditory nerve at the back of the brain.

Your sense of balance is so complex that the area of your brain that's purely dedicated to this one role involves the same number of cells as the rest of your brain cells put together.



The surfer's semicircular canals are as crucial as his feet when it comes to staying on his board

What are tonsils for?

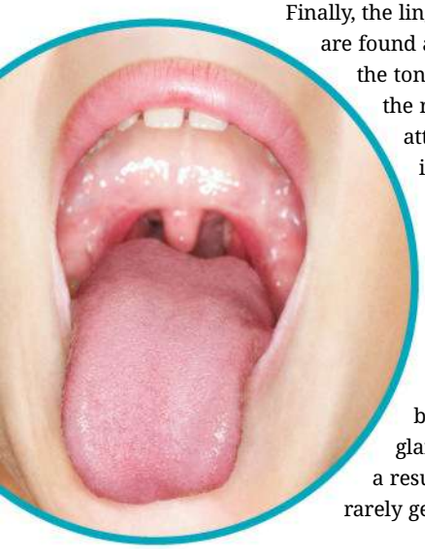
What purpose do these fleshy lumps in the back of our throats serve?

Tonsils are the small masses of flesh found in pairs at the back of the throats of many mammals. In humans the word is actually used to describe three sets of this spongy lymphatic tissue: the lingual tonsils, the pharyngeal tonsils and the more commonly recognised palatine tonsils.

The palatine tonsils are the oval bits that hang down from either side at the back of your throat – you can see them if you open your mouth wide in the mirror. Although the full purpose of the palatine tonsils isn't yet understood, because they produce antibodies and because of their prominent position in the throat, they're thought to be the first line of defence against potential infection in both the respiratory and digestive tracts.

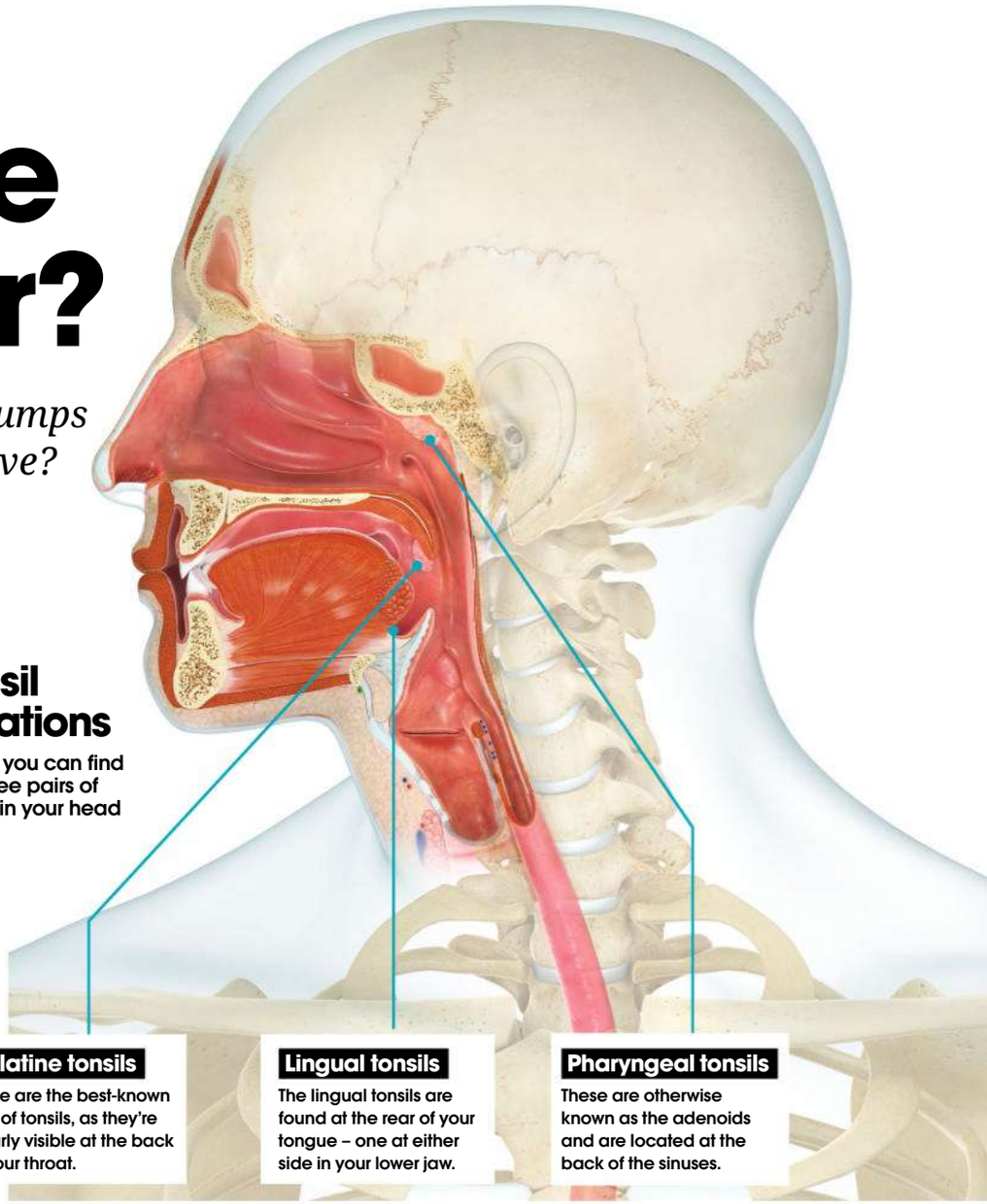
The pharyngeal tonsils are also known as the adenoids. These are found tucked away in the nasal pharynx and serve a similar purpose to the palatine tonsils but shrink in adulthood.

Finally, the lingual tonsils are found at the back of the tongue towards the root where it attaches and, if you poke your tongue right out, you should be able to spot them. These are drained very efficiently by mucous glands and, as a result, they very rarely get infected.



Tonsil locations

Where you can find the three pairs of tonsils in your head



Palatine tonsils
These are the best-known pair of tonsils, as they're clearly visible at the back of your throat.

Lingual tonsils
The lingual tonsils are found at the rear of your tongue – one at either side in your lower jaw.

Pharyngeal tonsils
These are otherwise known as the adenoids and are located at the back of the sinuses.

Lots of bed rest, fluids and pain relief like paracetamol are all recommended for treating tonsillitis

Tonsillitis in focus

Tonsillitis is usually caused by certain bacteria (eg group A beta-haemolytic streptococci) or sometimes a viral infection. Usually rest and a course of antibiotics will see it off, but occasionally the infection is very severe and can potentially cause serious problems, or reoccurs very frequently. In these cases a tonsillectomy may be considered – a surgical procedure where the tonsils are removed.

The adenoids are less commonly infected but, when they are, they become inflamed and swell to obstruct breathing through the nose and interfere with drainage from the sinuses, which can lead to further infections. In childen, constant breathing through the mouth can stress the facial bones and cause deformities as they grow, which is why they will sometimes have their adenoid glands removed.

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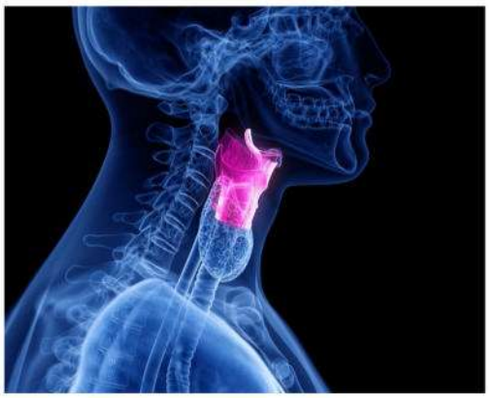
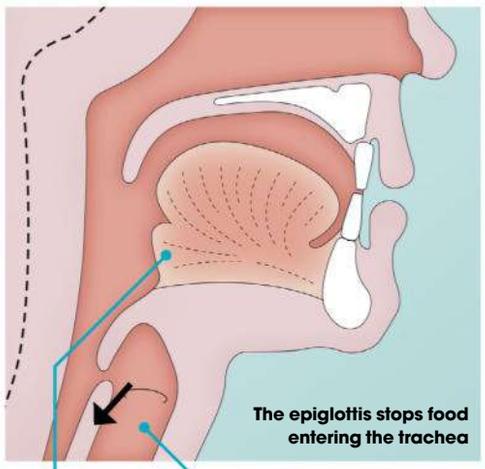
How do humans speak?

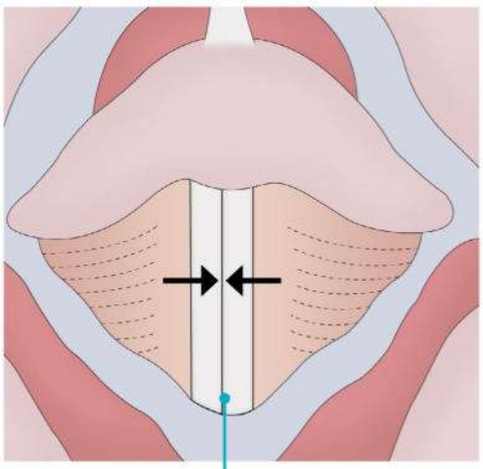
The vocal cords and larynx in particular have evolved over time to enable humans to produce a dramatic range of sounds in order to communicate – but how do they work?

Vocal cords, also known as vocal folds, are situated in the larynx, which is placed at the top of the trachea. They are layers of mucous membranes that stretch across the larynx and control how air is expelled from the lungs in order to make certain sounds. The primary usage of vocal cords within humans is in order to be abl to communicate with eachother and it is hypothesised that human vocal cords actually developed to the extent we see now to facilitate advanced levels of communication in response to the formation of social groupings during phases of primate, and specifically human, evolution.

As air is expelled from the lungs, the vocal folds vibrate and collide to produce a range of sounds. The type of sound emitted is effected by exactly how the folds collide, move and stretch as air passes over them. An individual 'fundamental frequency' is determined by the length, size and tension of their vocal cords. Movement of the vocal folds is controlled by the vagus nerve, and sound is then further fine-tuned to form words and sounds that we can recognise by the larynx, tongue and lips. Fundamental frequency in males averages at 125Hz, and at 210Hz in females. Children have a higher average pitch at around 300Hz.



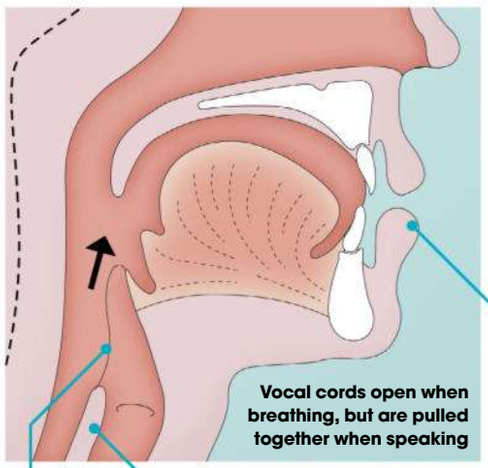


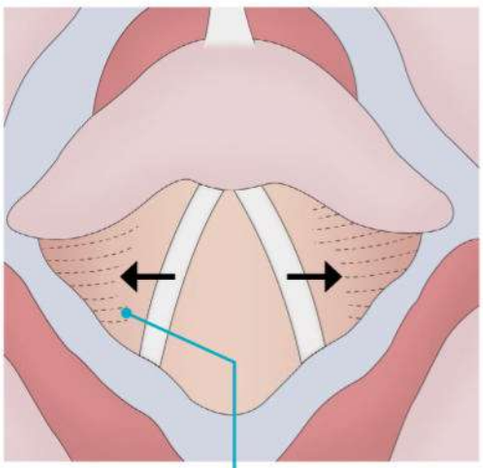


Tongue
This muscle, situated in the mouth, can affect and change sound as it travels up from the vocal cords and out through the mouth.

Trachea
The vocal cords are situated at the top of the trachea, which is where air from the lungs travels up through from the chest.

Vocal cords
These layers of mucous membranes stretch across the larynx and they open, close and vibrate to produce different sounds.





Epiglottis
This is a flap of skin that shuts off the trachea when an individual is swallowing food. It stops food and liquids 'going down the wrong way'.

Oesophagus
This tube, situated behind the trachea, is where food and liquid travels down to the stomach.

Lips
Lips are essential for the production of specific sounds, like 'b' or 'p'.

Larynx
Known as the voice box, this protects the trachea and is heavily involved in controlling pitch and volume. The vocal cords are situated within the larynx.

Anatomy of the neck

Explore one of the most complex and functional areas of the human body

The human neck is a perfect blend of form and function. It has several specific tasks (eg making it possible to turn our heads to see), while serving as a conduit for other vital activities (eg connecting the mouth to the lungs).

The anatomical design of the neck would impress modern engineers. The flexibility of the cervical spine allows your head to rotate, flex and tilt many thousands of times a day.

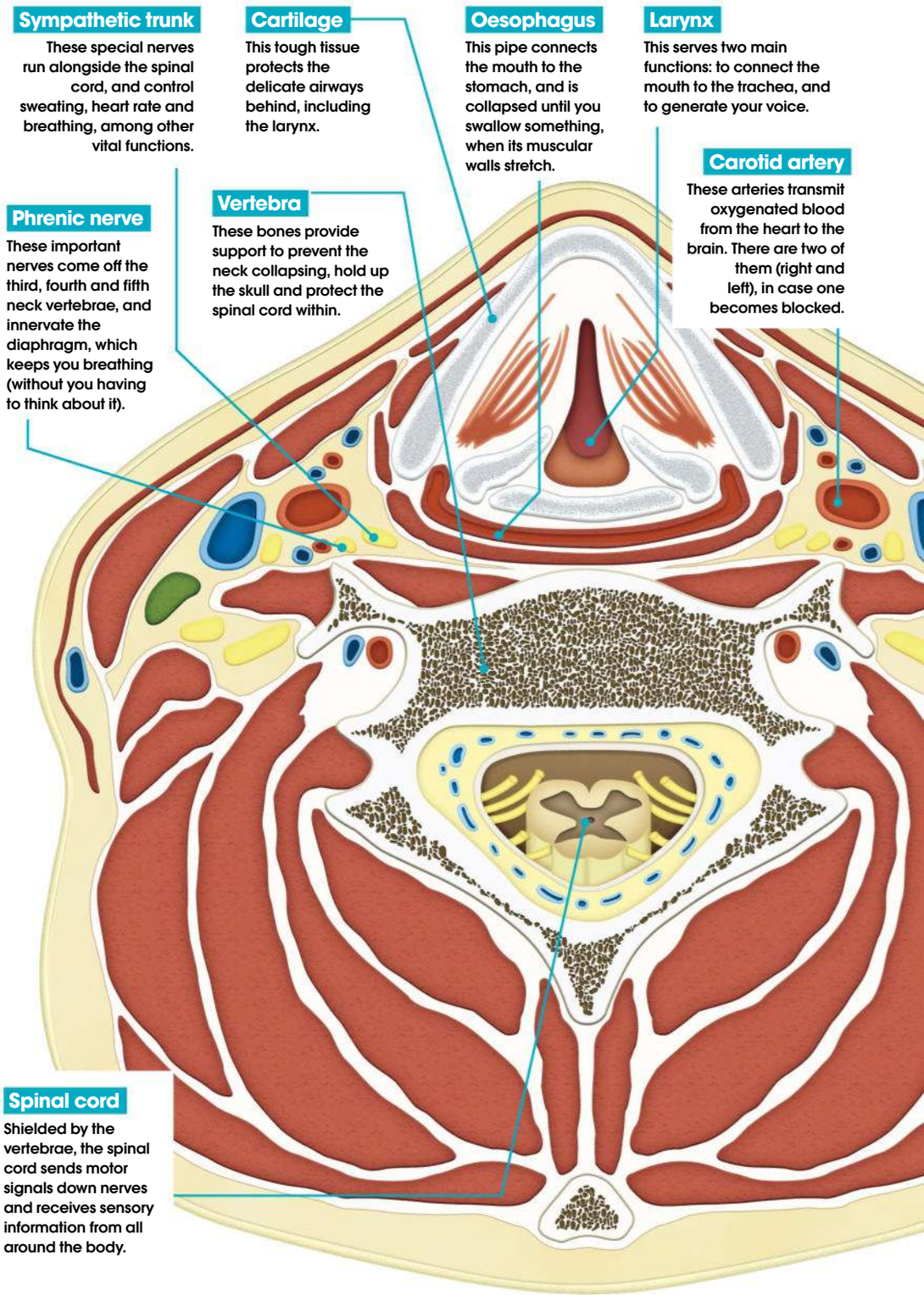
The muscles and bones provide the strength and flexibility required, however the really impressive design comes with the trachea, oesophagus, spinal cord, myriad nerves and the vital blood vessels. These structures must all find space and function perfectly at the same time. They must also be able to maintain their shape while the neck moves.

These structures are all highly adapted to achieve their aims. The trachea is protected by a ring of strong cartilage so it doesn't collapse, while allowing enough flexibility to move when stretched. Above this, the larynx lets air move over the vocal cords so we can speak. Farther back, the oesophagus is a muscular tube which food and drink pass through en route to the stomach. Within the supporting bones of the neck sits the spinal cord, which transmits the vital nerves allowing us to move and feel. The carotid arteries and jugular veins, meanwhile, constantly carry blood to and from the brain.

"The flexibility of the cervical spine allows your head to rotate"

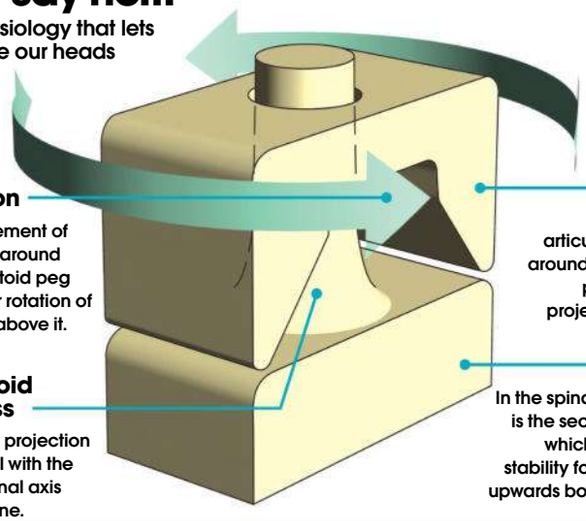
Get it in the neck

We show the major features that are packed into this junction between the head and torso



Just say no...

The physiology that lets us shake our heads



Rotation
The movement of the atlas around the odontoid peg allows for rotation of the skull above it.

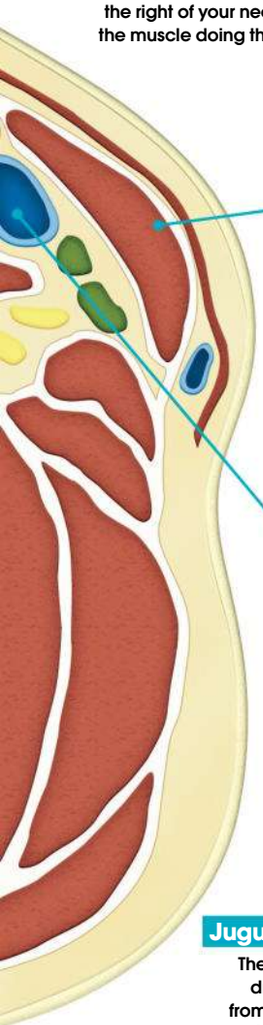
Odontoid process
This bony projection is parallel with the longitudinal axis of the spine.

Atlas
This section articulates (moves) around the odontoid process which projects through it.

Axis
In the spinal column, this is the second vertebra, which provides the stability for the required upwards bony projection.

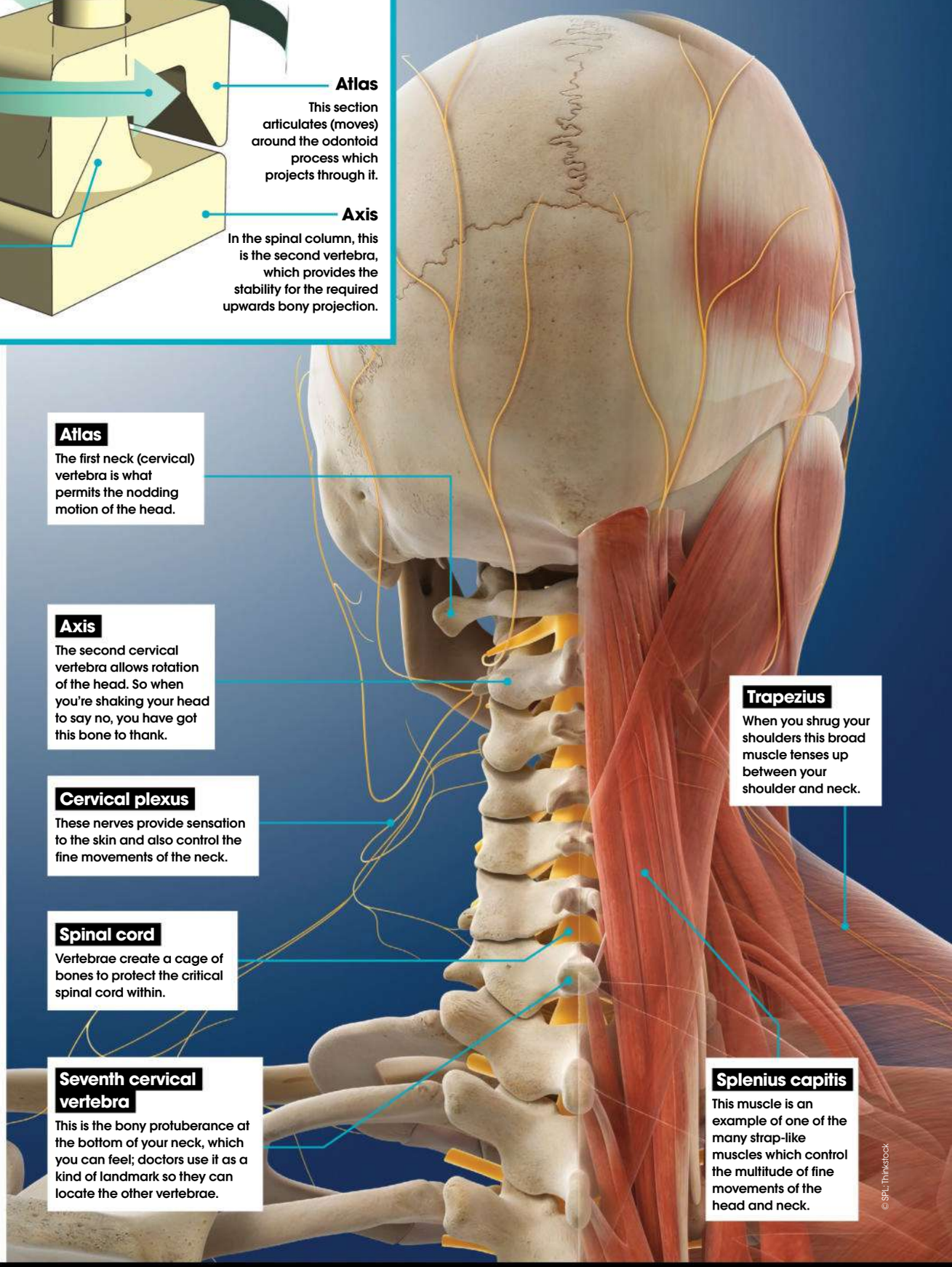
The neck in context

The human neck relies on a wide array of bones and muscles for support, as we see here



Sternocleidomastoid
Turn your head left and feel the right of your neck – this is the muscle doing the turning.

Jugular vein
These vessels drain blood from the neck, returning it to the heart.



Atlas
The first neck (cervical) vertebra is what permits the nodding motion of the head.

Axis
The second cervical vertebra allows rotation of the head. So when you're shaking your head to say no, you have got this bone to thank.

Cervical plexus
These nerves provide sensation to the skin and also control the fine movements of the neck.

Spinal cord
Vertebrae create a cage of bones to protect the critical spinal cord within.

Seventh cervical vertebra
This is the bony protuberance at the bottom of your neck, which you can feel; doctors use it as a kind of landmark so they can locate the other vertebrae.

Trapezius
When you shrug your shoulders this broad muscle tenses up between your shoulder and neck.

Splenius capitis
This muscle is an example of one of the many strap-like muscles which control the multitude of fine movements of the head and neck.

© SPL/Thinkstock

The human spine

The human spine is made up of 33 vertebrae, but how do they support our bodies while also allowing us such flexibility?

The human spine is made up of 33 vertebrae, 24 of which are articulated (flexible) and nine of which normally become fused. They are situated between the base of the skull to the pelvis, where the spine trails off into the coccyx (the tail bone).

The primary functions of the spine is to support the torso and head, which protect vital nerves and the spinal cord and allow the individual to move. By sitting closely together, separated only by thin intervertebral discs which work as ligaments and effectively form joints between the bones, the vertebrae form a strong pillar structure which holds the head up and allows for the body to remain upright. It also produces a base for ribs to attach to and to protect vital internal organs.

Vertebrae are not all fused together because of the need to move, and the vertebrae themselves are grouped into five types – cervical, thoracic, lumbar, sacral and coccygeal. The sacral vertebrae fuse as we mature and become solid bones towards the base of the spine. The coccygeal vertebrae will fuse in some cases, but they often remain separate. Collectively they are referred to as the coccyx. The rest of the vertebrae remain individual and discs between them allow them to move without wearing the bones down. The cervical vertebrae in the neck allow particularly extensive movement. The thoracic are far more static, with ties to the rib cage resisting much movement. The lumbar vertebrae allow modest side-to-side movement and rotation. The spine is curved to allow distribution of the body's weight, to ensure no one vertebrae takes the full impact.

C1 (atlas)

This is the vertebrae which connects the spinal column with the skull. It is named 'atlas' after the legend of Atlas who held the entire world on his shoulders.

Cervical vertebrae

These are the smallest of the articulating vertebrae, and support the head and neck. There are seven vertebrae, with C1, C2 and C7's structures quite unique from the others. They sit between the skull and thoracic vertebrae.

C2 (axis)

C2 is the pivot for C1 (atlas), and nearly all movement for shaking your head will occur at this joint – the atlanto-axial joint.

Thoracic vertebrae

The thoracic vertebrae are the intermediately sized vertebrae. They increase in size as you move down the spine, and they supply facets for ribs to attach to – this is how they are primarily distinguished.

Intervertebral discs

These discs form a joint between each vertebrae and, effectively, work as ligaments while also serving as fantastic shock absorbers. They facilitate movement and stop the bones rubbing together.

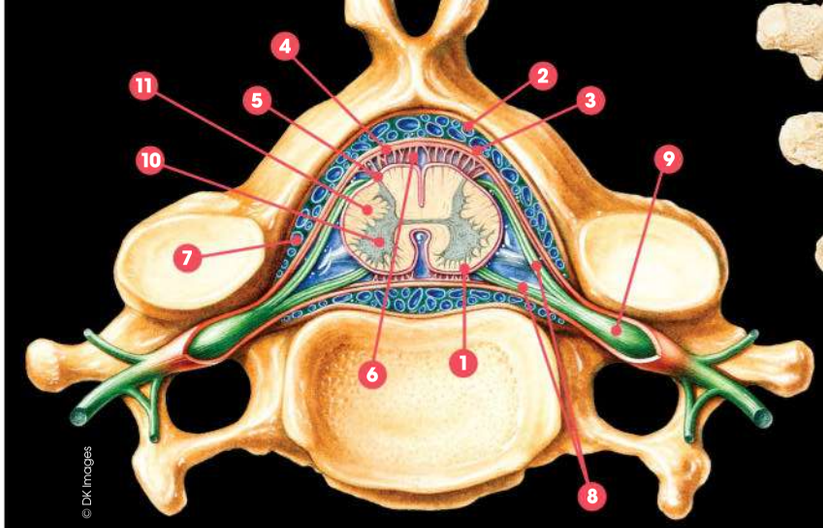
Spine curvature

As you look at the human spine, you can see some distinct curves. The primary reasons for these are to help distribute weight throughout the spine and support certain aspects of the body. The curve most familiar to us is the lumbar curve, between the ribs and pelvis. This develops when we start to walk at about 12-18 months and helps us with weight distribution during locomotion. Prior to this we develop the cervical curve, which allows us to support the weight of our head at around three-four months, and two smaller less-obvious curves in the spine (the thoracic and pelvic curves) are developed during gestation.

Spinal cords and nerves

The human spinal cord is an immensely complex structure made up of nerve cells and a large amount of supporting, protective tissue. It splits into 31 different sections and stretches 43-45cm, down from the brain to between the first and second lumbar vertebrae. Although more commonly referred to in respect of the brain, there is both white and grey matter present in the centre of the spinal cord. White matter contains axons tracts surrounded by fats, and blood vessels to protect them. The grey matter contains more of the neural cell bodies, such as dendrites, more axons and glial cells.

Spinal cord injuries are normally caused by trauma. If the trauma causes intervertebral discs and vertebrae to break, they can pierce the spinal cord, which can result in loss of feeling. Cord severance may result in paralysis.



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Spinal column cross-section

1 Spinal cord
This is an immensely important pathway for information to transfer between the brain and the body's nervous system. It is heavily protected by tissue and vertebrae, as any damage to it can be fatal.

2 Epidural space
This is the space between the outer protective tissue layer, dura mater and the bone. It is filled with adipose tissue (fat), while also playing host to numerous blood vessels.

3 Dura mater
This is the tough outer layer of tissue that protects the spinal cord. The three layers of protection between the vertebrae and the spinal cord are called the spinal meninges.

4 Arachnoid mater
Named for its spider web appearance, this is the second layer of the tissue protection provided for the spinal cord.

5 Pia mater
This thin, delicate layer sits immediately next to the spinal cord.

6 Subarachnoid space
This is the space between the pia mater and the arachnoid mater, which is filled with cerebrospinal fluid.

7 Blood vessels
Four arteries, which form a network called the Circle of Willis, deliver oxygen-rich blood to the brain. The brain's capillaries form a lining called the 'blood-brain barrier', which controls blood flow to the brain.

8 Dorsal and ventral roots
These connect the spinal nerves to the spinal cord, allowing transition of information between the brain and the body.

9 Spinal nerves
Humans have 31 pairs of spinal nerves all aligned with individual vertebrae, and these communicate information from around the body to the spinal cord. They carry all types of information – motor, sensory and so on – and are commonly referred to as 'mixed spinal nerves'.

10 Grey matter
Within the hom-like shapes in the centre of the spinal cord, sit most of the important neural cell bodies. They are protected in many ways, including by the white matter.

11 White matter
This area that surrounds the grey matter holds axon trails, but is primarily made up of lipid tissue (fats) and blood vessels.

© SPL

Lumbar vertebrae
Lumbar vertebrae are the largest of the vertebrae and the strongest, primarily because they withstand the largest pressures. Compared with other vertebrae they are more compact, lacking facets on the sides of the vertebrae.

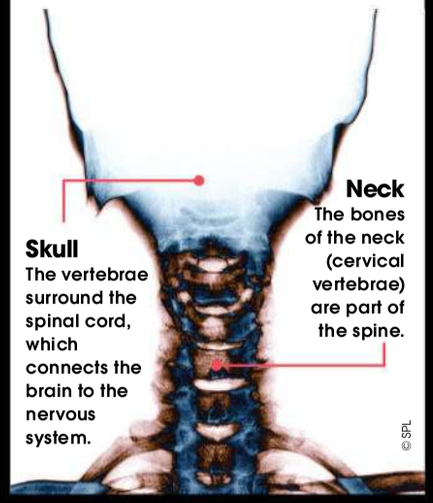
Sacral vertebrae
We have five sacral vertebrae at birth, but by maturity they will have fused to form a solid bone, which helps support the lumbar vertebrae and connect the coccyx to the spine.

Coccyx (tailbone)
The coccyx can display between three and five vertebrae. They're commonly thought to be fused, but often are not. Although these vertebrae are a vestigial remnant of a tail, they have several uses, such as supporting weight when sitting.

Articulated vertebrae enable maximum flexibility

How is the skull attached to the spine?

The skull is connected to the spine by the atlanto-occipital joint, which is created by C1 (atlas) and the occipital bone situated at the base of the cranium (skull). This unique vertebra has no 'body' and actually looks more like a ring than any other vertebra. It sits at the top of the cervical vertebrae and connects with the occipital bone via an ellipsoidal joint, allowing movement such as nodding or rotation of the head. An ellipsoidal joint is where an ovoid connection (in this case the occipital bone) is placed into an elliptical cavity (C1 vertebrae). The rest of the cervical vertebrae also work to support the weight of the head.



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Hormones

How the human endocrine system develops and controls the human body

The ductless glands in the endocrine system use chemicals called hormones to communicate with and control the cells in our bodies. They secrete different types of hormones directly into the bloodstream which then target specific organs.

The target organs contain hormone receptors that respond to the chemical instructions supplied by the hormone. There are 50 different types of hormone in the body and they all consist of three basic types: peptides, amines and steroids.

Steroids include the testosterone hormone. This is not only secreted by the cortex of the adrenal gland, but also from the male and female reproductive organs and by the placenta in pregnant women. The majority of hormones are called peptides that consist of short chains of amino acids. They are secreted by the pituitary and parathyroid glands. Amine hormones are secreted by the thyroid and adrenal medulla and are related to initiating the fight or flight response.

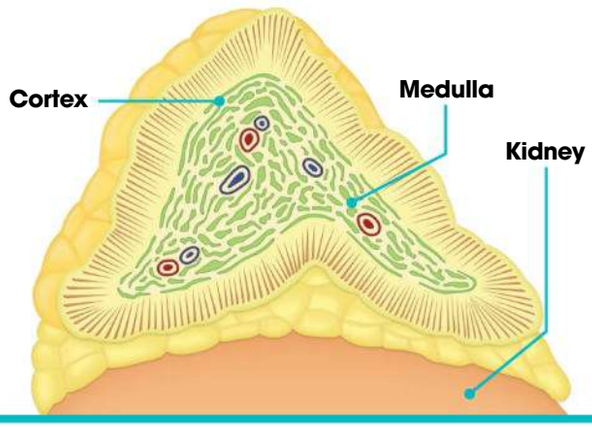
The changes caused by the endocrine system are slower than the nervous system. They regulate growth, moods, metabolism, reproductive processes and a maintain homeostasis for the body. The pituitary, thyroid and adrenal glands form the major elements of the endocrine system along with the male testes, the female ovaries and the pancreas.

Adrenal gland

We have two adrenal glands that are positioned on top of both kidneys. The triangular-shaped glands each consist of a two-centimetre thick outer cortex that produces steroid hormones, which include testosterone, cortisol and aldosterone.

The ellipsoid shaped, inner part of the gland is known as the medulla, which produces noradrenaline and adrenaline. These hormones increase the heart rate, and the body's levels of oxygen and glucose while reducing non-essential body functions.

The adrenal gland is known as the 'fight or flight' gland as it controls how we respond to stressful situations, and prepares the body for the demands of either fighting or running away as fast as you can. Prolonged stress over-loads this gland and causes illness.



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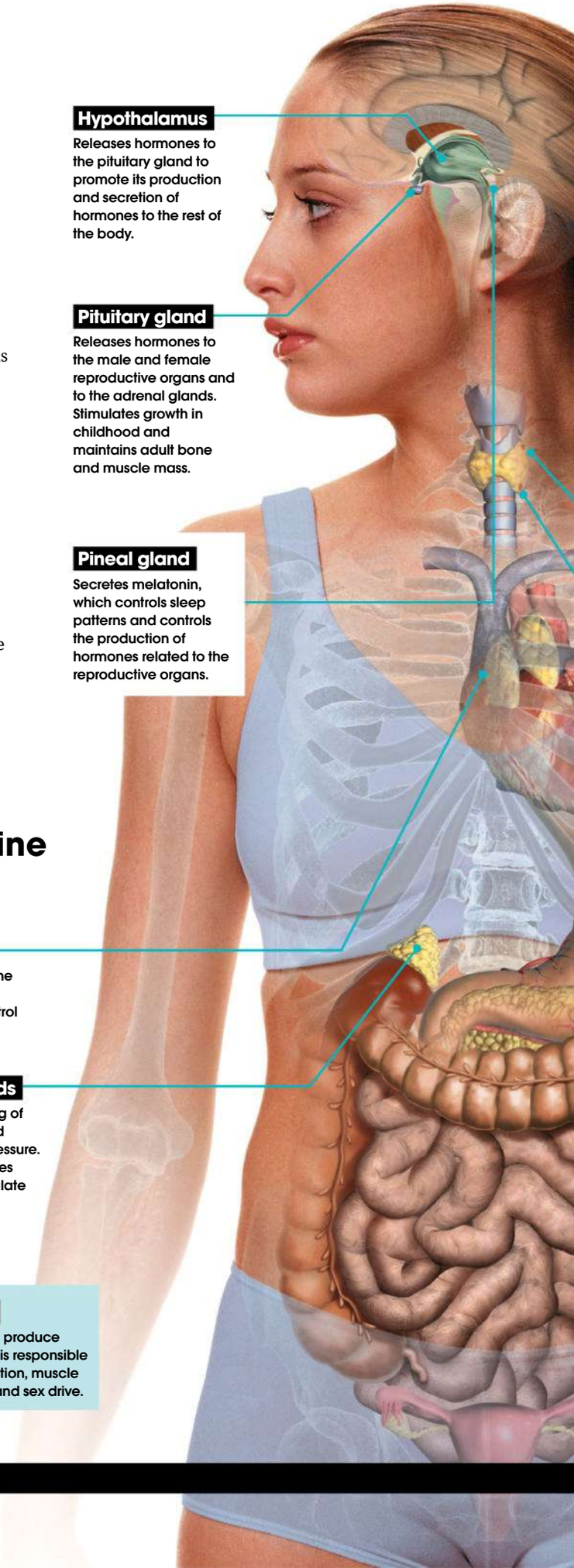
The endocrine system



Hypothalamus
Releases hormones to the pituitary gland to promote its production and secretion of hormones to the rest of the body.

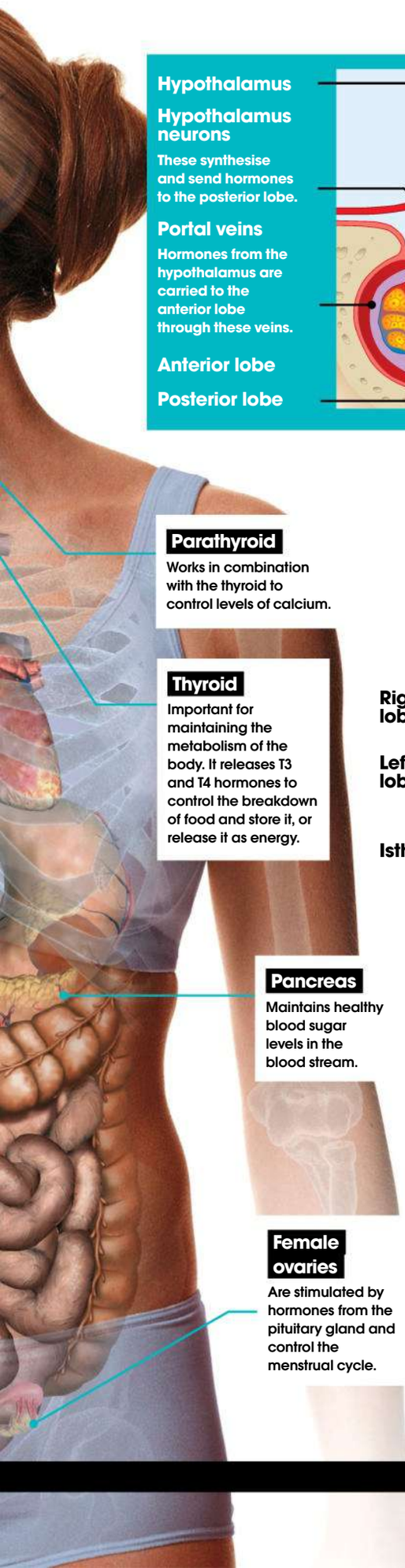
Pituitary gland
Releases hormones to the male and female reproductive organs and to the adrenal glands. Stimulates growth in childhood and maintains adult bone and muscle mass.

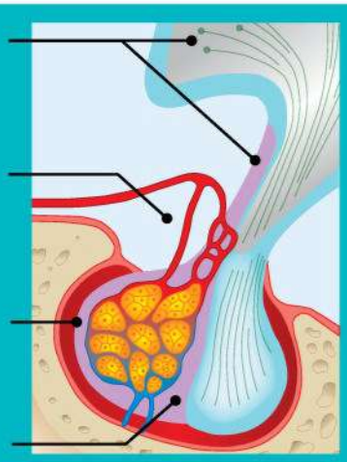
Pineal gland
Secretes melatonin, which controls sleep patterns and controls the production of hormones related to the reproductive organs.

Thymus
Is part of the immune system. It produces thymosins that control the behaviour of white blood T-cells.

Adrenal glands
Controls the burning of protein and fat, and regulates blood pressure. The medulla secretes adrenaline to stimulate the fight or flight response.

Male testes
These two glands produce testosterone that is responsible for sperm production, muscle and bone mass and sex drive.





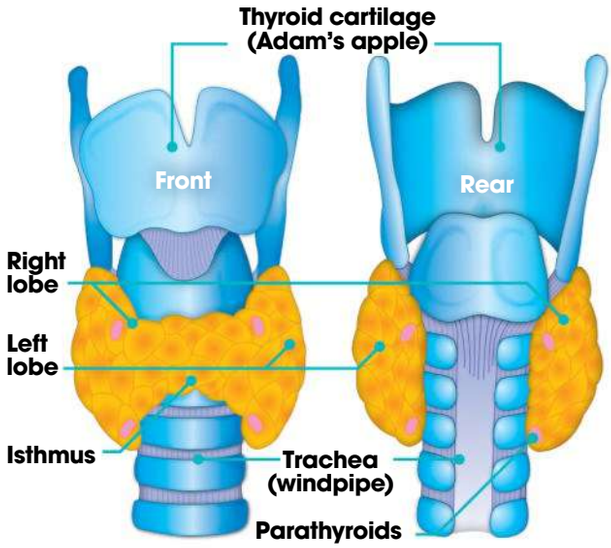
Pituitary gland

The pea-sized pituitary gland is a major endocrine gland that works under the control of the hypothalamus. The two organs inside an individuals brain work in concert and mediate feedback loops in the endocrine system to maintain control and stability within the body.

The pituitary gland features an anterior (front) lobe and a posterior (rear) lobe. The anterior lobe secretes growth hormones that stimulate the development of the muscles and bones; it also stimulates the development of ovarian follicles in the female ovary. In males, it is this that actually stimulates the production of sperm cells. The posterior lobe stores vasopressin and oxytocin that is supplied by the hypothalamus. Vasopressin allows the retention of water in the kidneys and suppresses the need to excrete urine. It also raises blood pressure by contracting the blood vessels in the heart and lungs.

Oxytocin influences the dilation of the cervix before giving birth and the contraction of the uterus after birth. The lactation of the mammary glands are stimulated by oxytocin when mothers begin to breastfeed.

Thyroid and parathyroids



The two lobes of the thyroid sit on each side of the windpipe and are linked together by the isthmus that runs in front of the windpipe. It stimulates the amount of body oxygen and energy consumption, thereby keeping the metabolic rate of the body at the current levels to keep you healthy and active.

The hypothalamus and the anterior pituitary gland are in overall control of the thyroid and they respond to changes in the body by either suppressing or increasing thyroid stimulating hormones. Overactive thyroids cause excessive sweating, weight loss and sensitivity to heat, whereas underactive thyroids cause sensitivity to hot and cold, baldness and weight gain. The thyroid can swell during puberty and pregnancy or due to viral infections or lack of iodine in a person's diet.

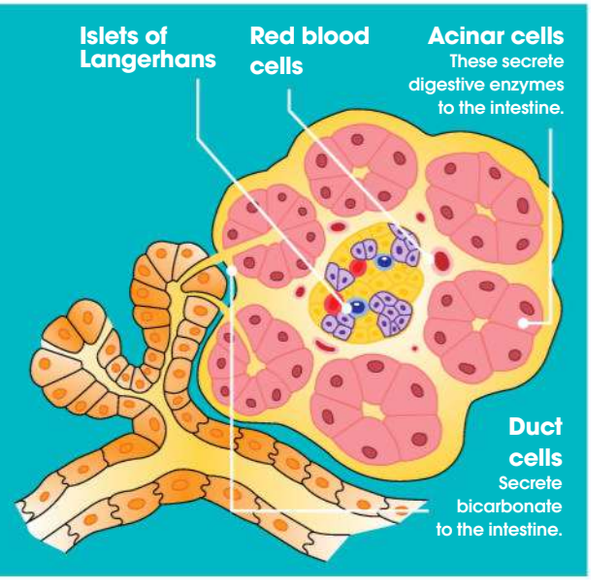
The four small parathyroids regulate the calcium levels in the body; it releases hormones when calcium levels are low. If the level of calcium is too high the thyroid releases calcitonin to reduce it. Therefore, the thyroid and parathyroids work in tandem.

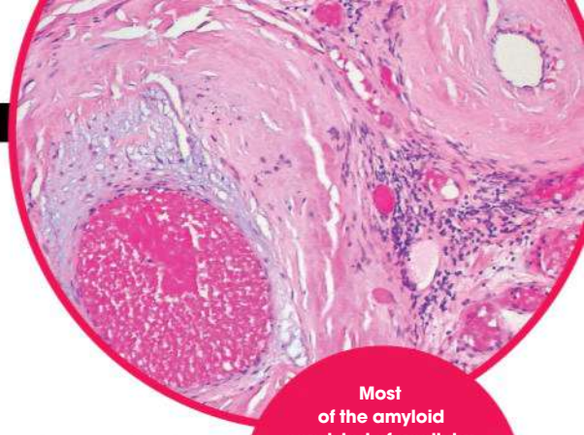
Pancreatic cells

The pancreas is positioned in the abdominal cavity above the small intestine. Consisting of two types of cell, the exocrine cells do not secrete their output into the bloodstream but the endocrine cells do.

The endocrine cells are contained in clusters called the islets of Langerhans. They number approximately 1 million cells and are only one or two per cent of the total number of cells in the pancreas. There are four types of endocrine cells in the pancreas. The beta cells secrete insulin and the alpha cells secrete glucagon, both of which stimulate the production of blood sugar (glucose) in the body. If the Beta cells die or are destroyed it causes type 1 diabetes, which is fatal unless treated with insulin injections.

The other two cells are the gamma and





Most of the amyloid consisted of acellular pink globules that effaced and expanded the node, but this image shows the characteristic involvement of blood vessel walls

Inside the circulatory system

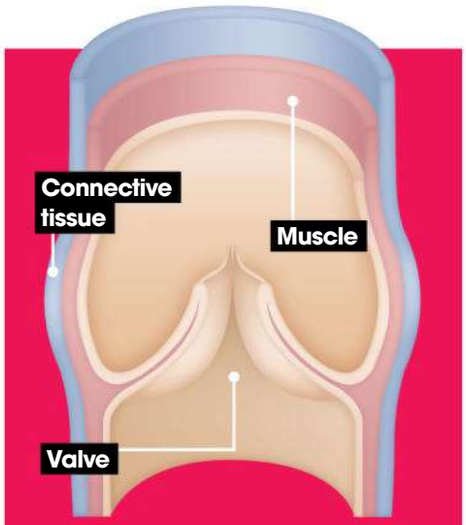
Arteries and veins form the plumbing system that carries blood around the body. Find out more about the circular journey it takes...

The network of blood vessels in the human body must cope with different volumes of blood travelling at different pressures. These blood vessels come in a multitude of different sizes and shapes, from the large, elastic aorta down to very tiny, one-cell-thick capillaries.

Blood is the ultimate multitasker. It carries oxygen for various tissues to use, nutrients to provide energy, removes waste products and even helps you warm up or cool down. It also carries vital clotting factors which stop us bleeding. Blood comes in just two varieties; oxygen-rich (oxygenated) blood is what the body uses for energy, and is bright red. After it has been used, this oxygen-depleted (deoxygenated) blood is returned for recycling and is actually dark red (not blue, as is often thought).

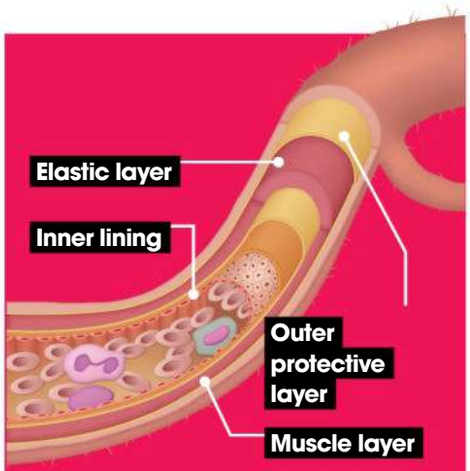
Blood is carried in vessels, of which there are two main different types – arteries and veins. Arteries carry blood away from the heart and deal with high pressures, and so have strong elastic walls. Veins carry blood back towards the heart and deal with lower pressures, so have thinner walls. Tiny capillaries connect arteries and veins together, like small back-roads connecting motorways to dual carriageways.

Arteries and veins are constructed differently to cope with the varying pressures, but work in tandem to ensure that the blood reaches its final destination. However, sometimes things go wrong, lead to certain medical problems: varicose veins from failing valves; deep vein thrombosis from blood clots blocking the deep venous system; heart attacks from blocked arteries; and lastly life-threatening aneurysms from weak artery walls.



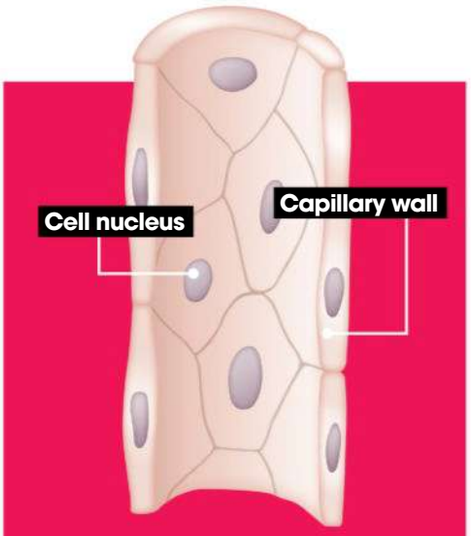
How do veins work?

Veins carry low pressure blood. They contain numerous one-way valves which stop backwards flow of blood, which can occur when pressure falls in-between heartbeats. Blood flows through these valves towards the heart but cannot pass back through them in the other direction. Valves can fail over time, especially in the legs. This leads to saggy, unsightly veins, known as varicose veins.



Arteries – under pressure!

Arteries cope with all of the pressure generated by the heart and deliver oxygen-rich blood to where it needs to be 24 hours a day. The walls of arteries contain elastic muscles, which allow them to stretch and contract to cope with the wide changes in pressure which is generated from the heart. Since the pressure is high, valves are unnecessary, unlike the low-pressure venous system.



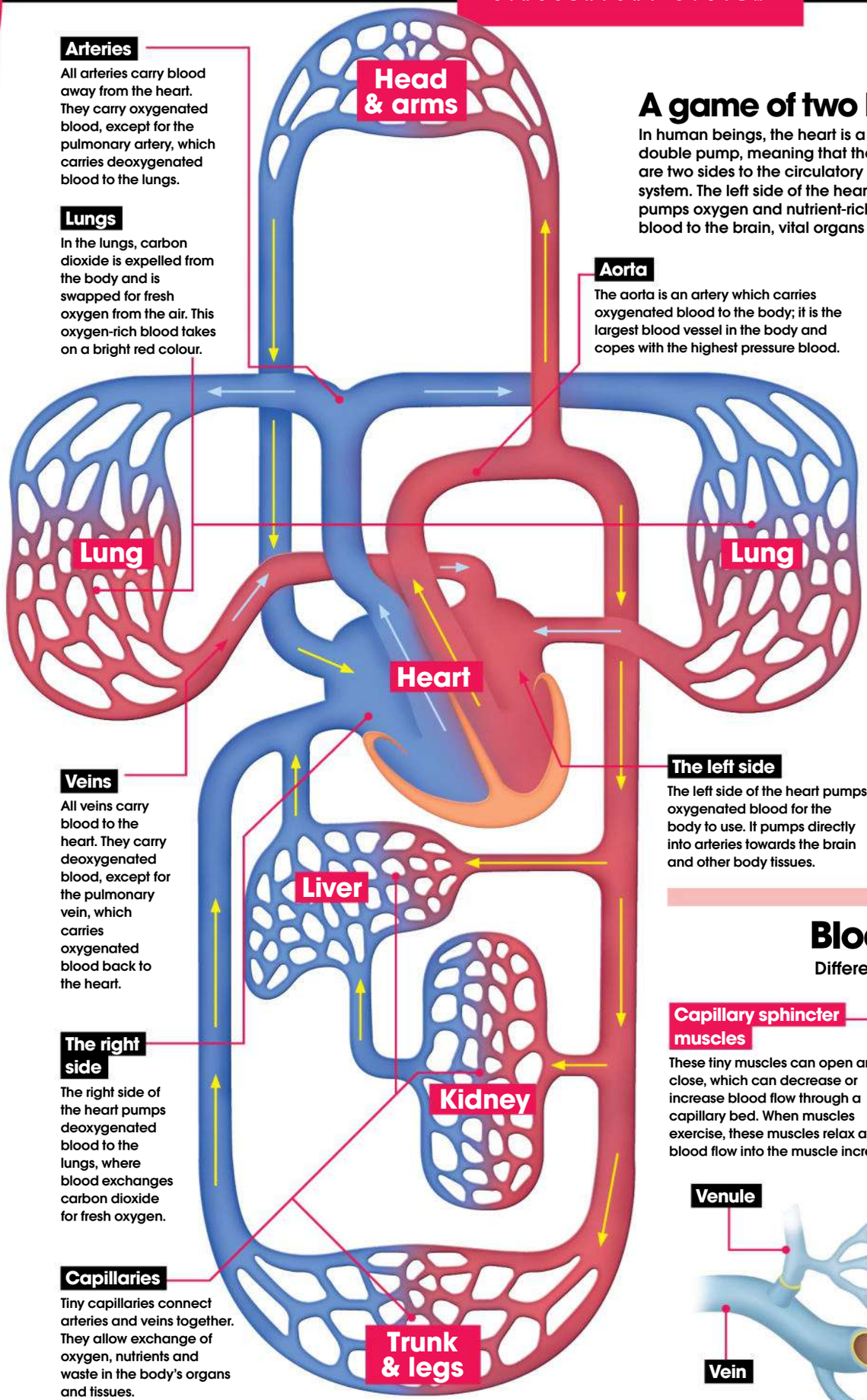
Connecting it all together

Capillaries are the tiny vessels which connect small arteries and veins together. Their walls are only one cell thick, so this is the perfect place to trade substances with surrounding tissues. Red blood cells within these capillaries trade water, oxygen, carbon dioxide, nutrients, waste and even heat. Because these vessels are only one cell wide, the cells have to line up to pass through.

© Ed Uthman, MD

Arteries
All arteries carry blood away from the heart. They carry oxygenated blood, except for the pulmonary artery, which carries deoxygenated blood to the lungs.

Lungs
In the lungs, carbon dioxide is expelled from the body and is swapped for fresh oxygen from the air. This oxygen-rich blood takes on a bright red colour.



Aorta
The aorta is an artery which carries oxygenated blood to the body; it is the largest blood vessel in the body and copes with the highest pressure blood.

Veins
All veins carry blood to the heart. They carry deoxygenated blood, except for the pulmonary vein, which carries oxygenated blood back to the heart.

The left side
The left side of the heart pumps oxygenated blood for the body to use. It pumps directly into arteries towards the brain and other body tissues.

The right side
The right side of the heart pumps deoxygenated blood to the lungs, where blood exchanges carbon dioxide for fresh oxygen.

Capillaries
Tiny capillaries connect arteries and veins together. They allow exchange of oxygen, nutrients and waste in the body's organs and tissues.

A game of two halves

In human beings, the heart is a double pump, meaning that there are two sides to the circulatory system. The left side of the heart pumps oxygen and nutrient-rich blood to the brain, vital organs and other body tissues (the systemic circulation). The right side of the heart pumps deoxygenated blood towards the lungs, so it can pick up new oxygen molecules to be used again (the pulmonary circulation).

"Plasma carries all of the different types of cells"

What's in blood?

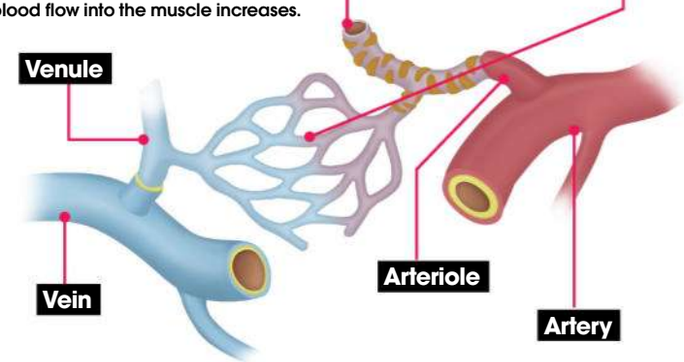
It's actually only the iron in red blood cells which make blood red – if you take these cells away then what you will be left with is a watery yellowish solution that is called plasma. Plasma carries all of the various different types of cells and also contains sugars, fats, proteins and salts. The main types of cell are red blood cells (which are formed from iron and haemoglobin, which carries oxygen around the body), white blood cells (which fight infection from bacteria, viruses and fungi) and finally platelets (which are actually tiny cell fragments which stop bleeding by forming clots at the sites of any damage).

Blood vessels

Different shapes and sizes

Capillary sphincter muscles
These tiny muscles can open and close, which can decrease or increase blood flow through a capillary bed. When muscles exercise, these muscles relax and blood flow into the muscle increases.

Capillary bed
This is the capillary network that connects the two systems. Here, exchange of various substances occurs with surrounding tissues, through the one-cell thick walls.



How your blood works

The science behind the miraculous fluid that feeds, heals and fights for your life

White blood cells

White blood cells, or leukocytes, are the immune system's best weapon, searching out and destroying bacteria and producing antibodies against viruses. There are five different types of white blood cells, all with distinct functions.

Platelet

When activated, these sticky cell fragments are essential to the clotting process. Platelets adhere to a wound opening to stem the flow of blood, then they team with a protein called fibrinogen to weave tiny threads that trap blood cells.

Red blood cell

Known as erythrocytes, red blood cells are the body's delivery service, shuttling oxygen from the lungs to living cells throughout the body and returning carbon dioxide as waste.

Blood vessel wall

Arteries and veins are composed of three tissue layers, a combination of elastic tissue, connective tissue and smooth muscle fibres that contract under signals from the sympathetic nervous system.

Granulocyte

The most numerous type of white blood cell, granulocytes patrol the bloodstream destroying invading bacteria by engulfing and digesting them, often dying in the process.

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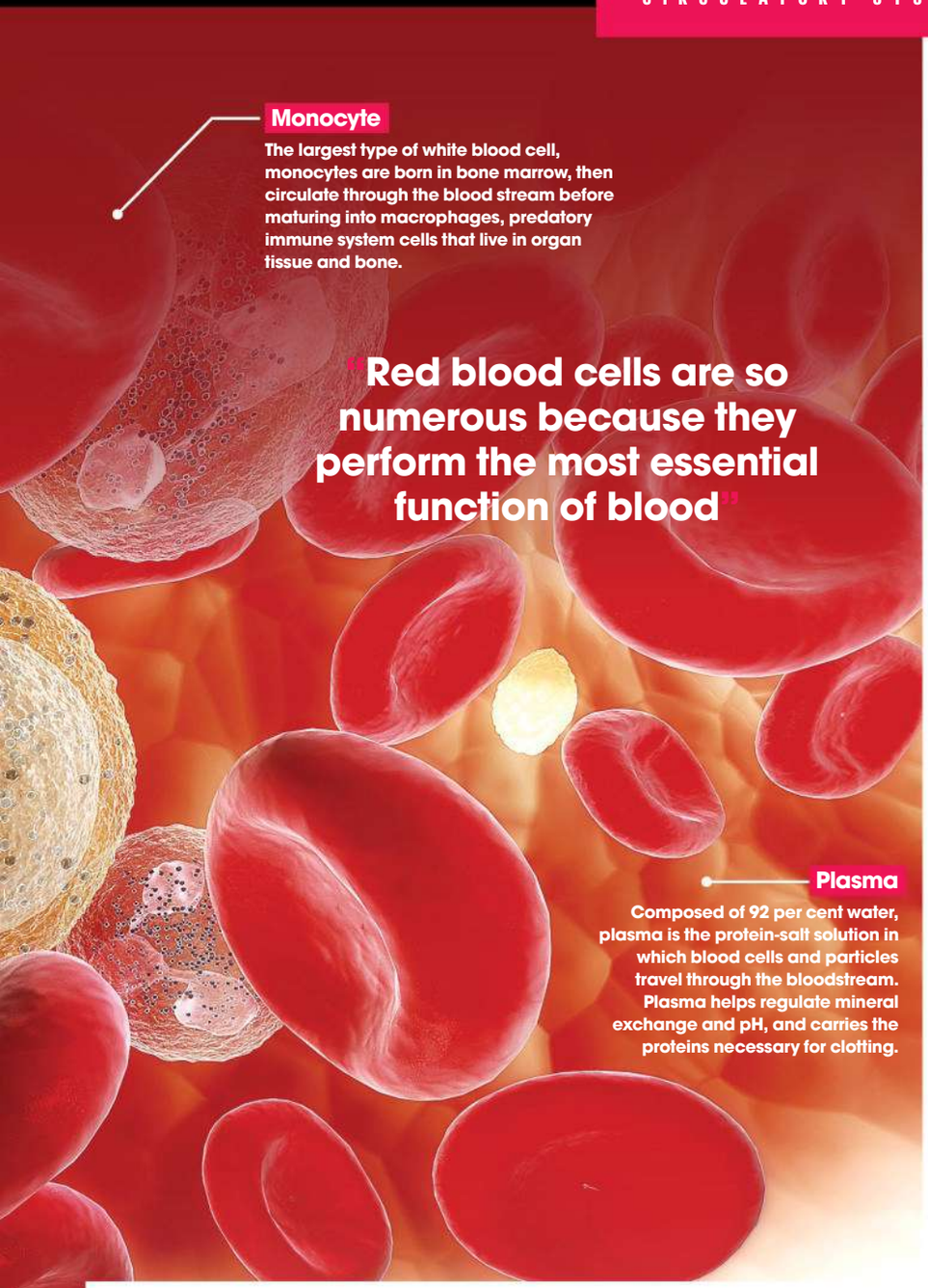
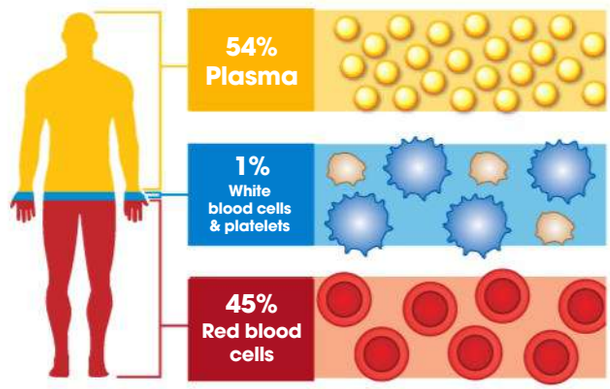
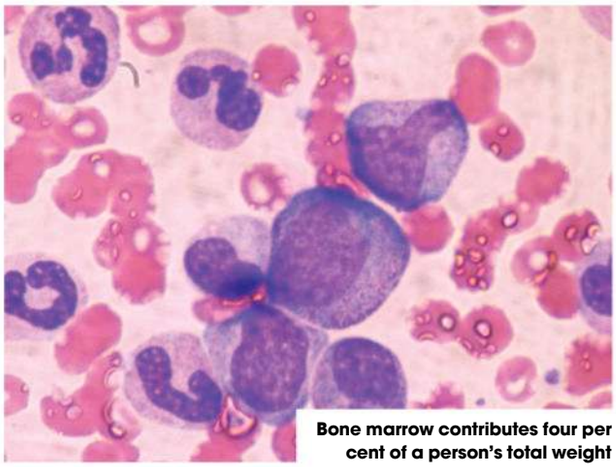


Components of blood

Blood is a mix of solids and liquids, a blend of highly specialised cells and particles suspended in a protein-rich fluid called plasma. Red blood cells dominate the mix, carrying oxygen to living tissue and returning carbon dioxide to the lungs. For every 600 red blood cells, there is a single white blood cell, of which there are five different kinds. Cell fragments called platelets use their irregular surface to cling to vessel walls and initiate the clotting process.





Bone marrow contributes four per cent of a person's total weight

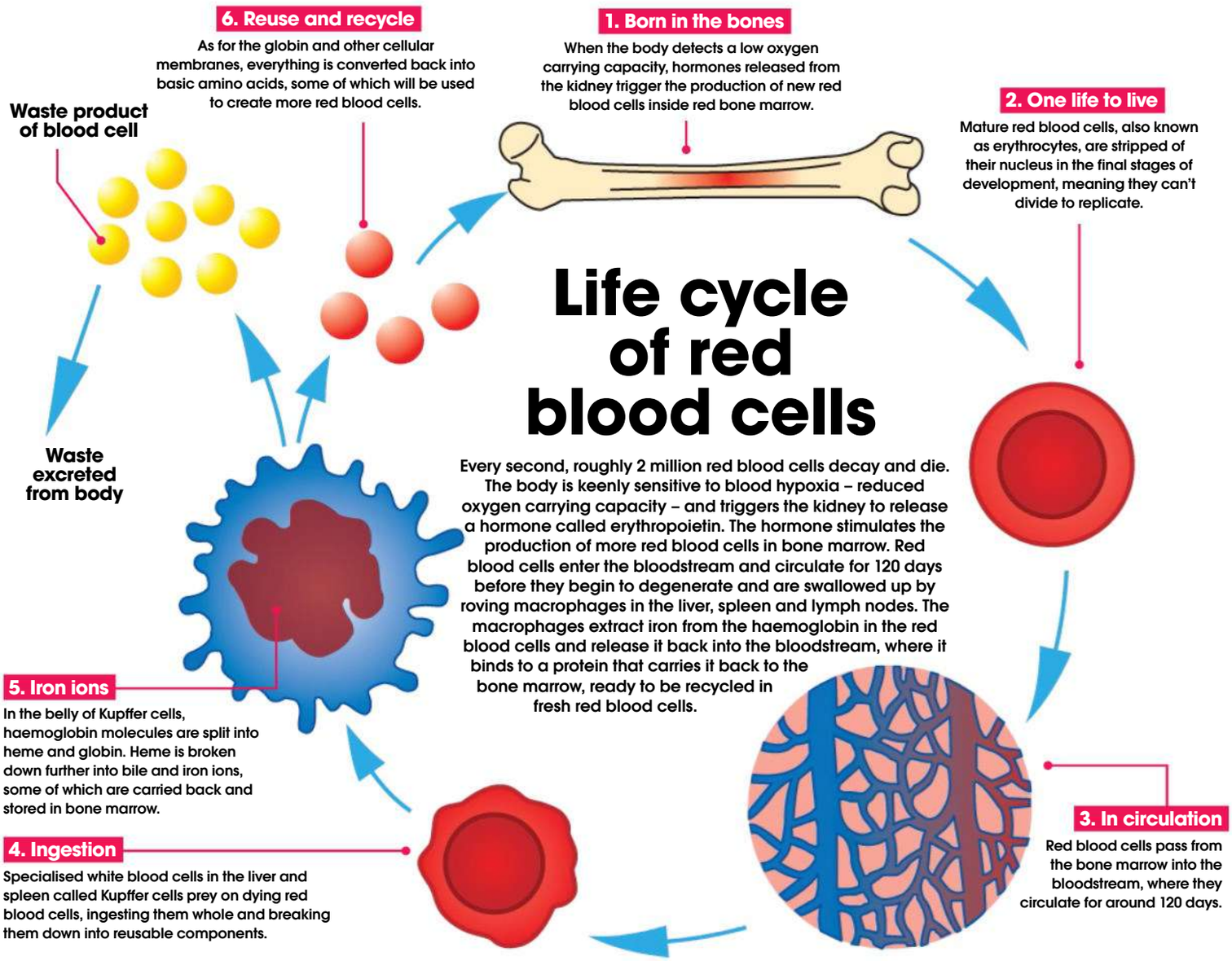
© Bobjgallindo

Blood is the river of life. It feeds oxygen and essential nutrients to living cells and carries away waste. It transports the foot soldiers of the immune system, white blood cells, which seek out and destroy invading bacteria and parasites. Then it speeds platelets to the site of injury or tissue damage, triggering the body's process of self-repair.

Blood looks like a thick, homogenous fluid, but it's actually more like a watery current of plasma – a straw-coloured, protein-rich fluid – carrying billions of microscopic solids consisting of red blood cells, white blood cells and cell fragments that are called platelets. The distribution is far from equal. Over half of our blood is plasma, 45 per cent is red blood cells and a tiny fragment, less than one per cent, is composed of white blood cells and platelets.

Red blood cells are so numerous because they perform the most essential function of blood, which is to deliver oxygen to every cell in the body and carry away carbon dioxide. As an adult, all of your red blood cells are produced in red bone marrow, the spongy tissue in the bulbous ends of long bones and at the centre of flat bones like hips and ribs. In the marrow, red blood cells start out as undifferentiated stem cells called hemocytoblasts. If the body detects a drop in oxygen carrying capacity, a hormone is released from the kidneys that triggers the stem cells to become red blood cells. Because red blood cells only live 120 days, the supply is continuously replenished; roughly 2 million red blood cells every second.

A mature red blood cell has no nucleus, it is spit out during the final stages of the two-day development before taking on the shape of a concave, doughnut-like disc. Red blood cells are mostly water, but 97 per cent of their solid matter is haemoglobin, a complex protein that carries four atoms of iron. Those iron atoms have the ability to form loose, reversible bonds with both oxygen and carbon dioxide – think of them as weak magnets – making red blood cells such an effective transport system for all of



the respiratory gasses. Haemoglobin, which turns bright red when oxygenated, is what gives blood its characteristic crimson colour.

To provide oxygen to every living cell, red blood cells must be pumped through the body's circulatory system. The right side of the heart pumps CO2-heavy blood into the lungs, where it releases its waste gasses and picks up oxygen. The left side of the heart then automatically pumps all of the freshly oxygenated blood out into the body through a system of various arteries and capillaries, some as narrow as a single cell. As the red blood cells release their oxygen, they pick up carbon dioxide molecules, then they course through the veins back toward the heart, where they are pumped back into the lungs to 'exhale' the excess CO2 and collect some more O2.

White blood cells are greatly outnumbered by red blood cells, but they are critical to the immune system. Most white blood cells are also produced in red bone marrow, but white blood cells – unlike red – come in five different varieties, each with its own specialised immune function. The first three varieties of blood cells, are called granulocytes, engulf and digest bacteria and parasites, and play a role in allergic reactions. Lymphocytes, another type of white blood cell, produce anti-bodies that build up our immunity to repeat intruders. And monocytes, the largest of the white blood cells, enter organ tissue and become macrophages, microbes that ingest bad bacteria and then help break down dead red blood cells into reusable parts.

Platelets aren't cells at all, they are actually tiny fragments from much larger stem cells found in bone marrow. In their resting state, they look like smooth oval plates, but when activated to form a clot they take on an irregular form with many protruding arms called pseudopods. This shape is what helps them to be able to stick not only to the blood vessel walls but also to each other, forming a physical barrier around wound sites. With the help of proteins and clotting factors that are found inside plasma, platelets weave a mesh of fibrin that stems blood loss and triggers the formation of new collagen and skin cells.

But even these three functions of blood – oxygen supplier, immune system defender and wound healer – only begin to scratch the surface of blood's critical role in every bodily process. When blood circulates through the small intestine, it absorbs sugars from digested food, which are transported to the liver to be stored as energy. When blood passes through the kidneys, it is scrubbed of excess urea and salts, waste that will leave the body as urine. The proteins transport vitamins, hormones, enzymes, sugar and electrolytes.

Blood disorders

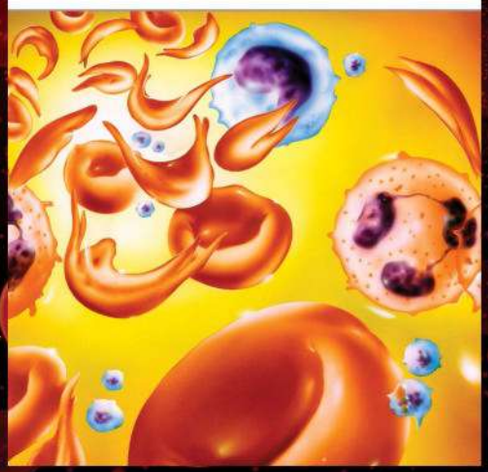
Blood is a delicate balancing act, with the body constantly regulating oxygen flow, iron content and clotting ability. Unfortunately, there are several genetic conditions and chronic illnesses that can disturb the balance, sometimes with deadly consequences

Haemophilia

This rare genetic blood disorder severely inhibits the clotting mechanism of blood, causing excessive bleeding, internal bruising and joint problems. Platelets are essential to the clotting and healing process, producing threads of fibrin with help from proteins in the bloodstream called clotting factors. People who suffer from haemophilia – almost exclusively males – are missing one of those clotting factors, making it difficult to seal off blood vessels after even minor injuries.

Sickle cell anaemia

Anaemia is the name for any blood disorder that results in a dangerously low red blood cell count. In sickle cell anaemia, which afflicts one out of every 625 children of African descent, red blood cells elongate into a sickle shape after releasing their oxygen. The sickle-shaped cells die prematurely, leading to anaemia, or sometimes lodge in blood vessels, causing terrible pain and even organ damage. Interestingly, people who carry only one gene for sickle cell anaemia are immune to malaria.



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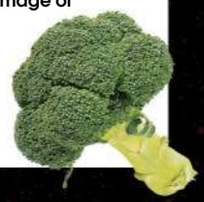
Thalassemia

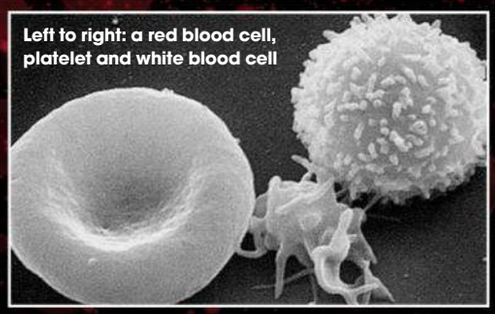
Another rare blood disorder affecting 100,000 newborns worldwide each year, thalassemia inhibits the production of haemoglobin, leading to severe anaemia. People who are born with the most serious form of the disease, also called Cooley's anaemia, suffer from enlarged hearts, livers and spleens, and brittle bones. The most effective treatment is frequent blood transfusions, although a few lucky patients have been cured through bone marrow transplants from perfectly matching donors.

Hemochromatosis

One of the most common genetic blood disorders, emochromatosis is the medical term for "iron overload," in which your body absorbs and stores too much iron from food. Severity varies wildly, and many people experience few symptoms, but others suffer serious liver damage or scarring(cirrhosis), irregular heartbeat, diabetes and even heart failure. Symptoms can be aggravated by taking too much vitamin C.



"Platelets weave a mesh of fibrin that stems blood loss"



Left to right: a red blood cell, platelet and white blood cell

Deep vein thrombosis

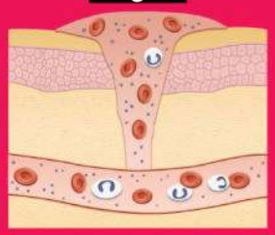
Thrombosis is the medical term for any blood clot that is large enough to block a blood vessel. When a blood clot forms in the large, deep veins of the upper thigh, it's called deep vein thrombosis. If such a clot breaks free, it can circulate through the bloodstream, pass through the heart and become lodged in arteries in the lung, causing a pulmonary embolism. Such a blockage can severely damage portions of the lungs, and multiple embolisms can even be fatal.

Blood and healing

More than a one-trick pony, your blood is a vital cog in the healing process

Think of blood as the body's emergency response team to an injury. Platelets emit signals that encourage blood vessels to contract, stemming blood loss. The platelets then collect around the wound, reacting with a protein in plasma to form fibrin, a tissue that weaves into a mesh. Blood flow returns and white blood cells begin their hunt for bacteria. Fibroblasts create beds of fresh collagen and capillaries to fuel skin cell growth. The scab begins to contract, pulling the growing skin cells closer together until damaged tissue is replaced.

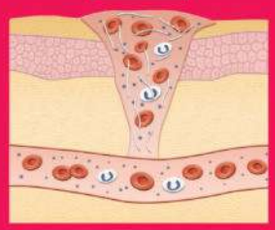
Stage 1



Injury

When the skin surface is cut, torn or scraped deeply enough, blood seeps from broken blood vessels to fill the wound. To stem the flow of bleeding, the blood vessels around the wound constrict.

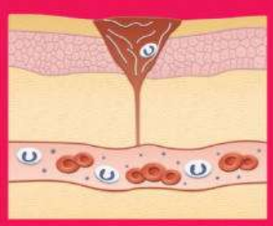
Stage 2



Haemostasis

Activated platelets aggregate around the surface of the wound, stimulating vasoconstriction. Platelets react with a protein in plasma to form fibrin, a web-like mesh of stringy tissue.

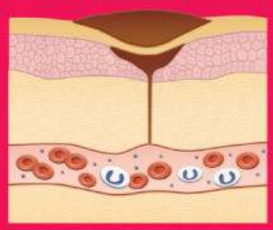
Stage 3



Inflammatory Stage

Once the wound is capped with a drying clot, blood vessels open up again, releasing plasma and white blood cells into the damaged tissue. Macrophages digest harmful bacteria and dead cells.

Stage 4



Proliferative Stage

Fibroblasts lay fresh layers of collagen inside the wound and capillaries begin to supply blood for the forming of new skin cells. Fibrin strands and collagen pull the sides of the wound together.

Inside a blood vessel

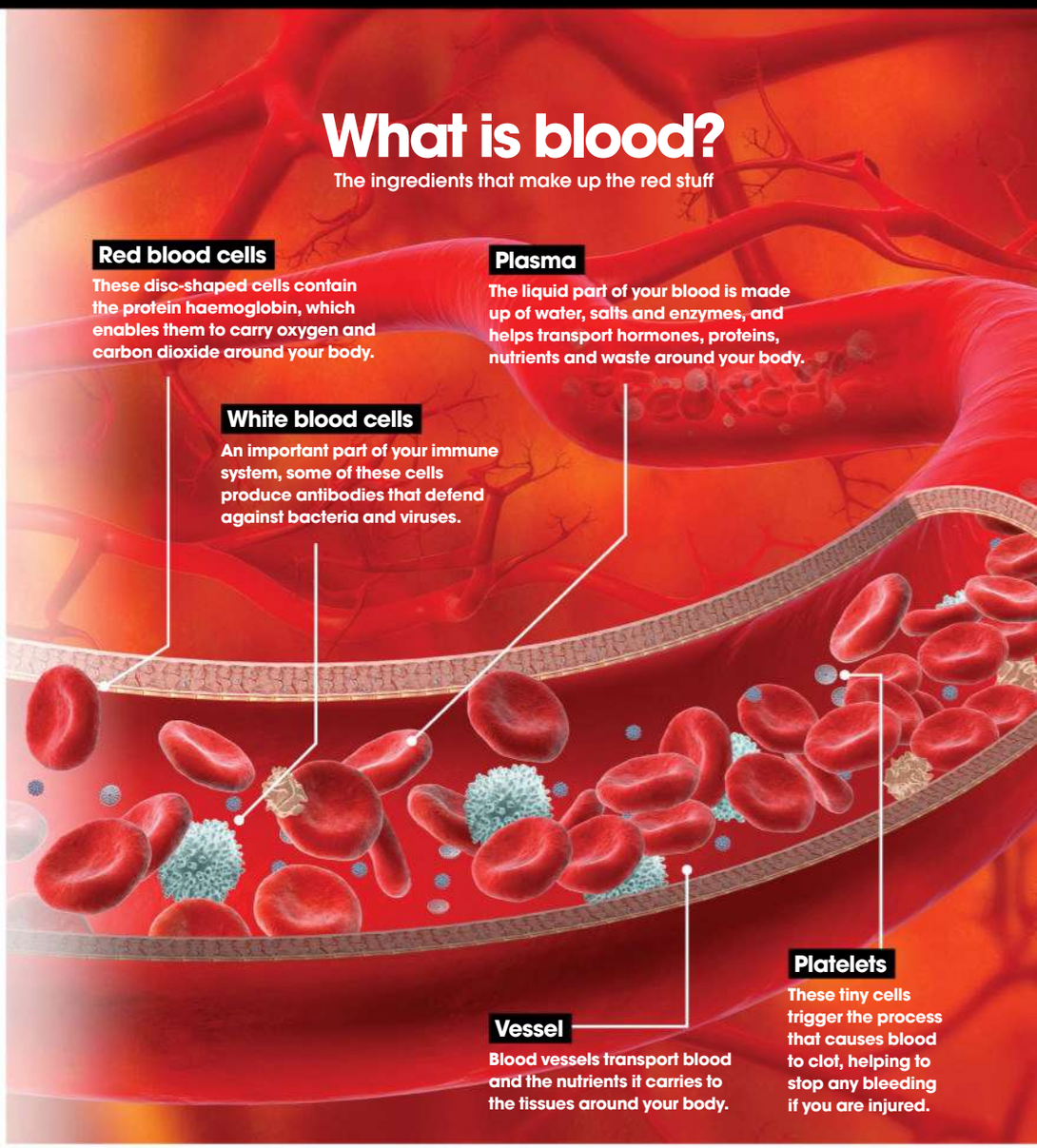
Discover what happens every time your heart beats

Inside your body there is a vast network of blood vessels that, if laid end to end, could easily wrap twice around the Earth. They carry the equivalent of more than 14,000 litres of blood around your body.

There are five main types of blood vessel. In general, arteries carry oxygenated blood away from the heart and have special elastic fibres in their walls to help squeeze it along when the heart muscle relaxes. The arteries then branch off into arterioles, which pass the blood into the capillaries, tiny blood vessels that transport nutrients from the blood into the body's tissues via their very thin walls.

As well as nourishing the tissue cells, capillaries also remove their waste products, passing the now deoxygenated blood on to the venules. These vessels drain the blood into the veins, which, with the help of valves that stop the blood flowing in the reverse direction, carry it back to the heart where it can pick up more oxygen.

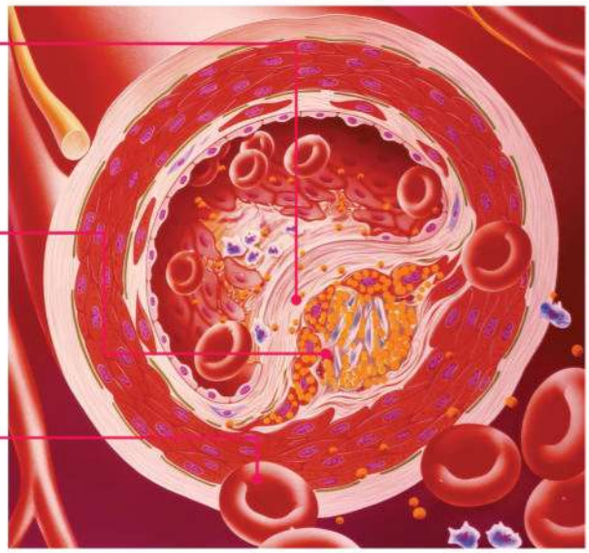
In contrast to the other blood vessels in the body, the pulmonary artery takes deoxygenated blood from the heart to the lungs, where it is oxygenated and carried back to the heart via the pulmonary veins.



Is cholesterol bad for you?

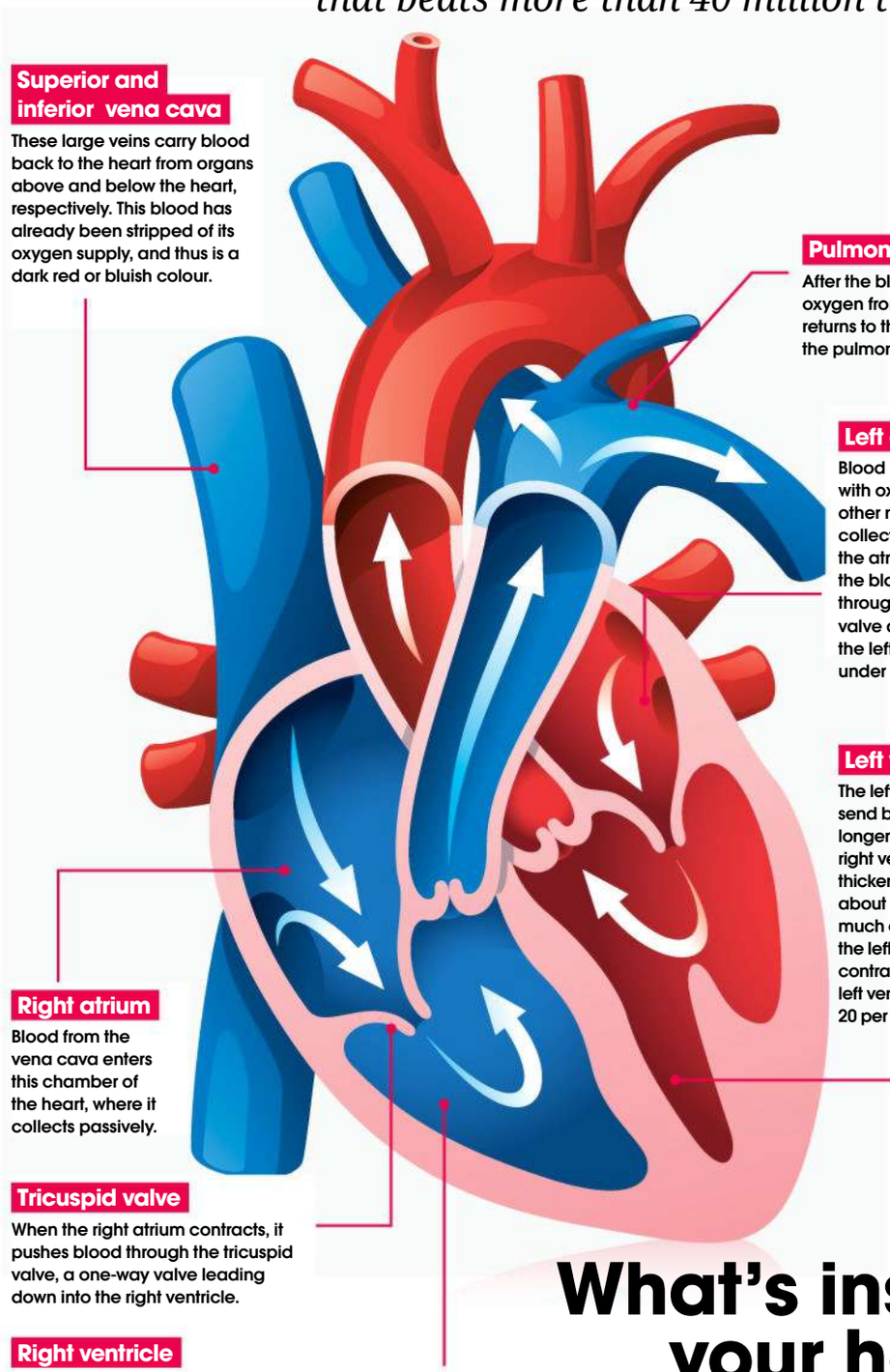
Is this substance as evil as we hear?

Cholesterol is a fatty molecule in the blood and, generally speaking, having too much is bad: it can stick to the walls of your arteries and increase the risk of heart disease. Most foods, with the exception of offal, eggs and shellfish, don't contain any cholesterol, but many contain saturated fats, which are turned into cholesterol by the liver. However, cholesterol itself isn't unhealthy – in fact, you wouldn't be able to live without it. The body uses cholesterol as a kind of padding, coating the outer membranes of all our cells and insulating nerve fibres, helping signals travel properly to and from the brain. It's also a fundamental part of the endocrine system, as all steroid hormones (eg oestrogen) are synthesised from cholesterol. A good diet and regular exercise can keep cholesterol within a healthy range for most people.



The heart – a vital organ

Your heart is a turbocharged double-pumping muscle that beats more than 40 million times every year



Superior and inferior vena cava
These large veins carry blood back to the heart from organs above and below the heart, respectively. This blood has already been stripped of its oxygen supply, and thus is a dark red or bluish colour.

Pulmonary veins
After the blood collects oxygen from the lungs, it returns to the heart via the pulmonary veins.

Left atrium
Blood brimming with oxygen and other nutrients collects here. When the atrium contracts, the blood passes through the mitral valve and enters the left ventricle under pressure.

Left ventricle
The left ventricle must send blood on a longer journey than the right ventricle, so it has thicker walls and uses about three times as much energy. Luckily, the left atrium's contraction gives the left ventricle's output a 20 per cent boost.

Right atrium
Blood from the vena cava enters this chamber of the heart, where it collects passively.

Tricuspid valve
When the right atrium contracts, it pushes blood through the tricuspid valve, a one-way valve leading down into the right ventricle.

Right ventricle
Blood enters the right ventricle under pressure from the atrium's contraction, giving it a boost much like the turbocharger in a high-performance car. The ventricle contracts and pumps blood through the pulmonary valve, into the pulmonary artery and toward the lungs.

What's inside your heart

Find out how your heart pumps blood around your body

Not only does your heart do amazing things, it does so tirelessly, from the moment you're born (actually, even a bit before then) to the instant that you die. It weighs somewhere between eight and 12 ounces – slightly more if you're male, less if you're female. Its sole purpose is to push blood through your circulatory system, providing crucial oxygen and other nutrients to all your organs.

The heart is considered a double pump because the right half sends 'used' blood to your lungs. There, the blood drops off a load of carbon dioxide and picks up some fresh oxygen, which you have helpfully provided by breathing. Then the oxygenated blood returns to the left half of the heart. This 'heart-to-lungs-to-heart-again' trip is known as pulmonary circulation. The left side of the heart then pumps this oxygenated blood to every organ in your body other than your lungs. Your brain, your skin, the muscles in your thigh, your spleen – they all get blood (and therefore oxygen) by virtue of your beating heart.

Even the heart itself gets blood, via a special set of veins and arteries known as the coronary system. The myocardial muscle within the wall of the heart needs oxygen and other nutrients to keep beating. Unfortunately, the coronary arteries that do this job are very narrow, between 1.7 and 2.2 millimetres in diameter. If they become clogged with cholesterol or other fatty deposits, the heart stops working.

Of course, the relatively simple concept of the double pump is fairly complex in practice. A series of valves control blood flow to the heart's four chambers, allow for the build-up of enough blood pressure to get the job done, and direct the blood to the correct veins and arteries.

The human heartbeat

How one of your hardest-working muscles keeps your blood pumping

Your heart began to beat when you were a four-week-old foetus in the womb. Over the course of the average lifetime, it will beat over 2 billion times.

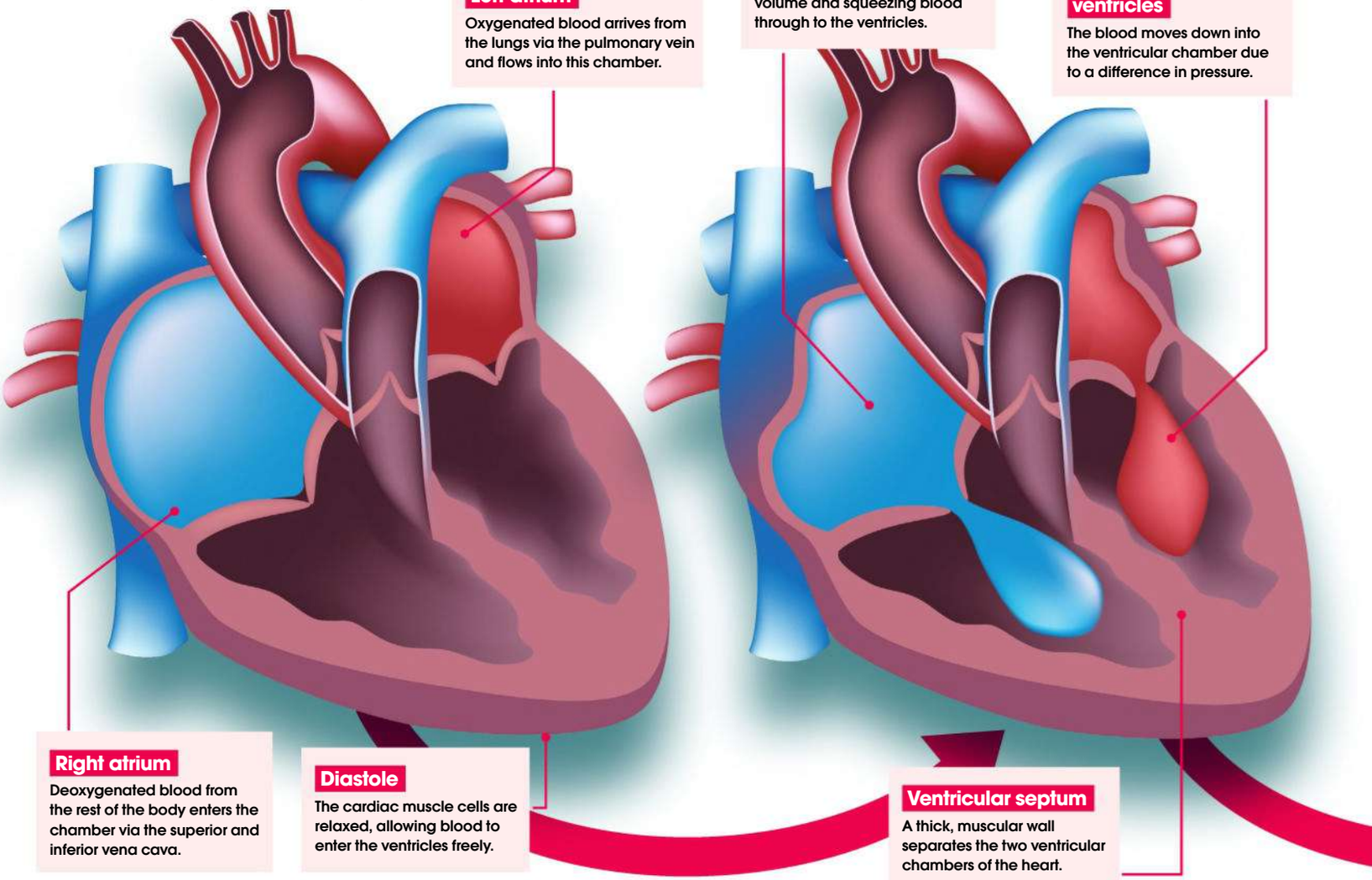
The heart is made of four chambers separated into two sides. The right side receives deoxygenated blood from the body, and pumps it towards the lungs, where it picks up oxygen from the air you breathe. The oxygenated blood returns to the left side of the heart, where it is sent through the circulatory system, delivering oxygen and nutrients around the body.

The heart's pumping action is coordinated by muscular contractions generated by electrical currents that trigger regular cardiac contractions called systole. The upper chambers – the atria – receive the blood and contract first. This forces blood to the lower chambers – the ventricles – which contract to push blood out to the body. After a brief stage where the heart tissue relaxes, known as diastole, the cycle repeats.

The heart consists of four chambers, separated into two sides

The cardiac cycle

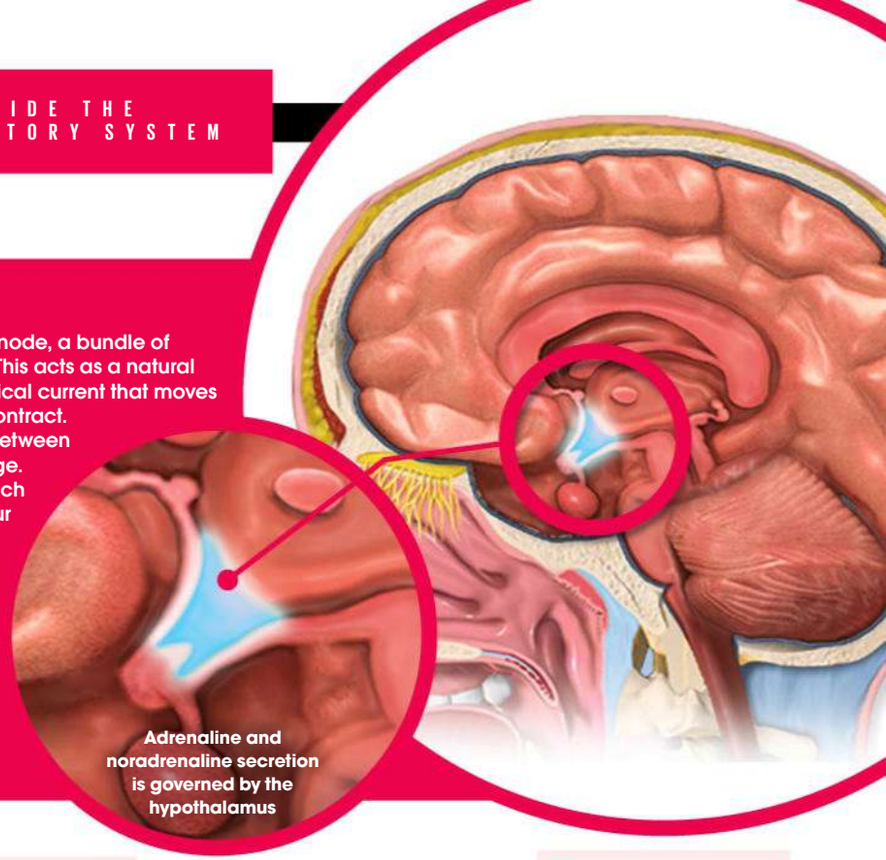
A single heartbeat is a series of organised steps that maximise blood-pumping efficiency



Fight or flight

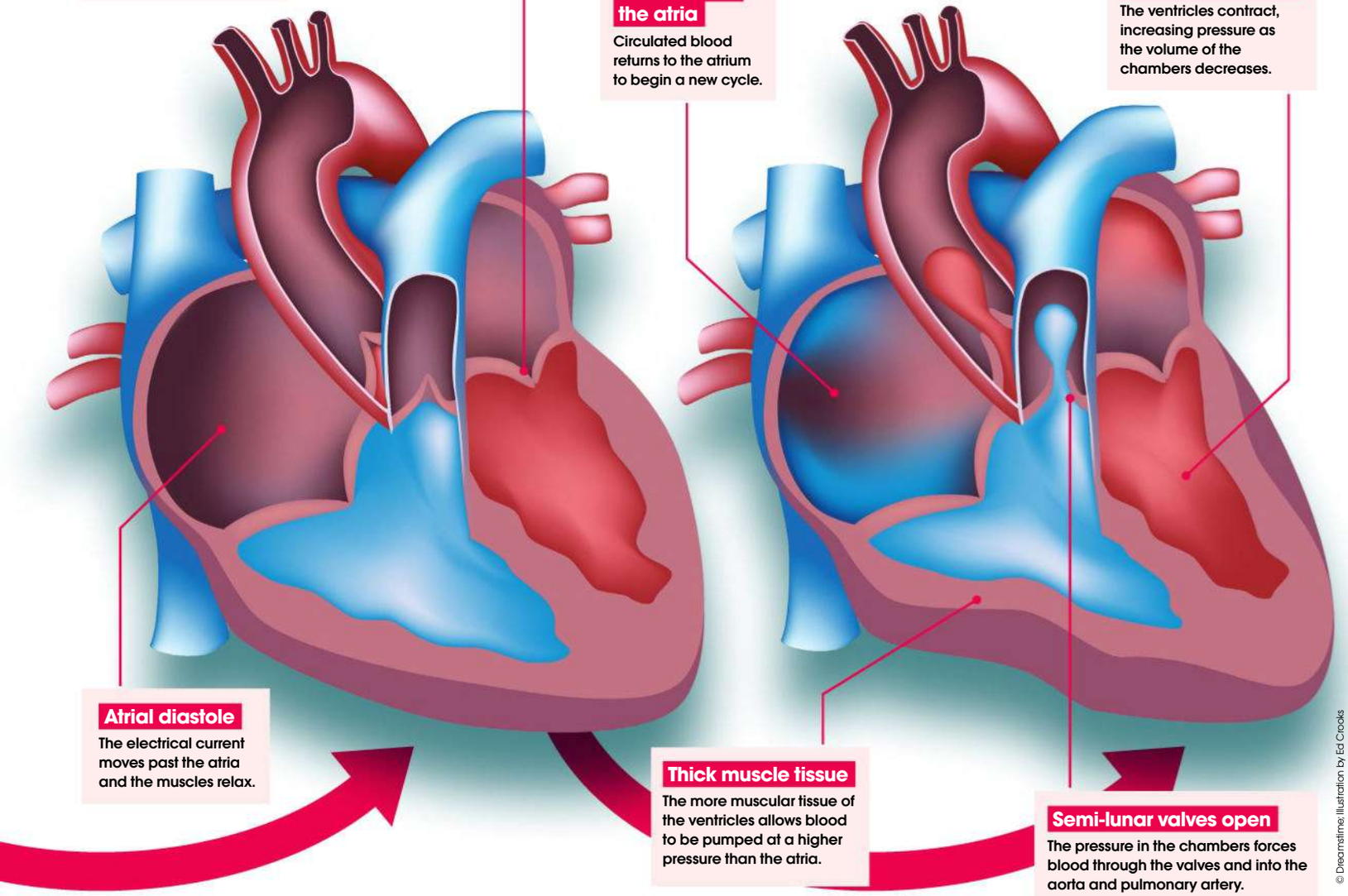
A heartbeat begins at the sinoatrial node, a bundle of specialised cells in the right atrium. This acts as a natural pacemaker by generating an electrical current that moves throughout the heart, causing it to contract. When you are at rest, this happens between 60 to 100 times per minute on average. Under stressful situations however, such as an encounter with a predator, your brain will automatically trigger a 'fight or flight' response.

This results in the release of adrenaline and noradrenaline hormones that change the conductance of the sinoatrial node, increasing heart rate, and so providing the body with more available nutrients to either fight for survival or run for the hills.



Adrenaline and noradrenaline secretion is governed by the hypothalamus

"Over the course of the average lifetime, the heart will beat over 2 billion times"



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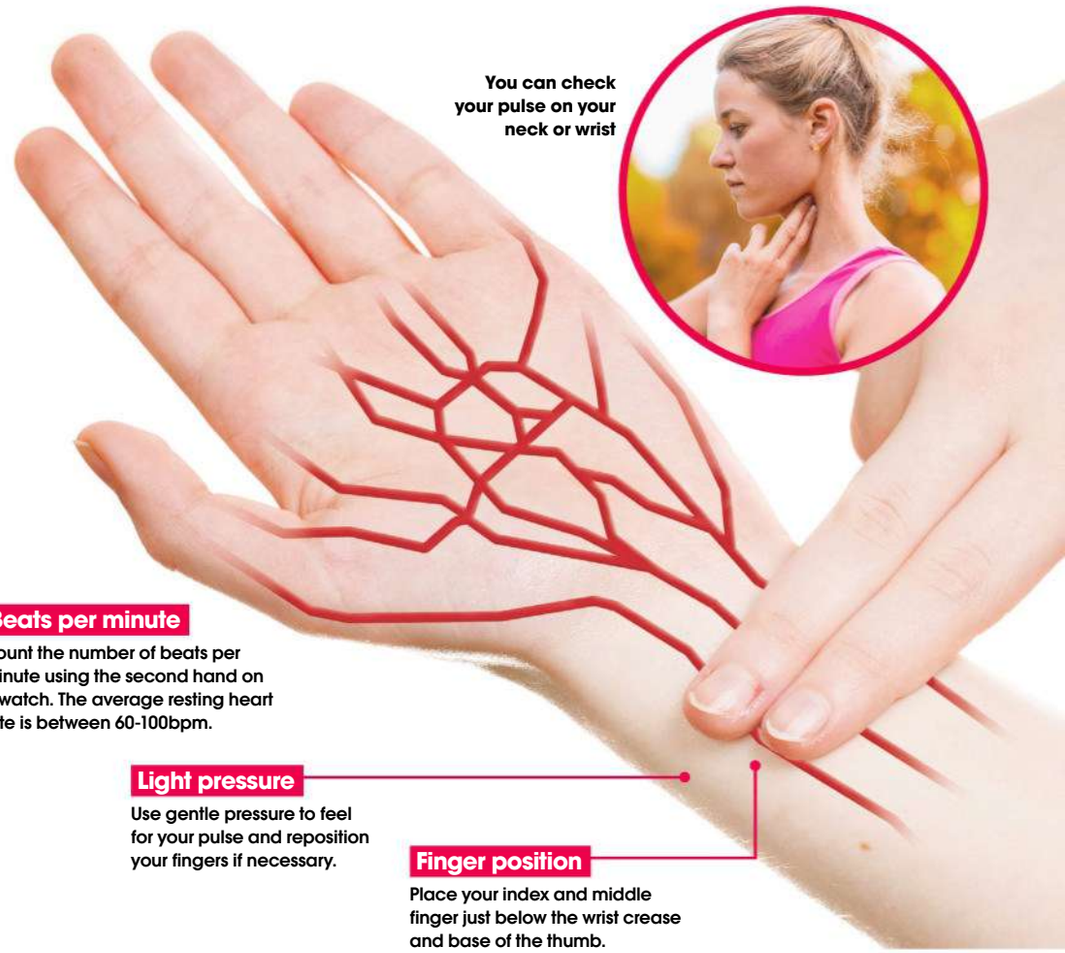
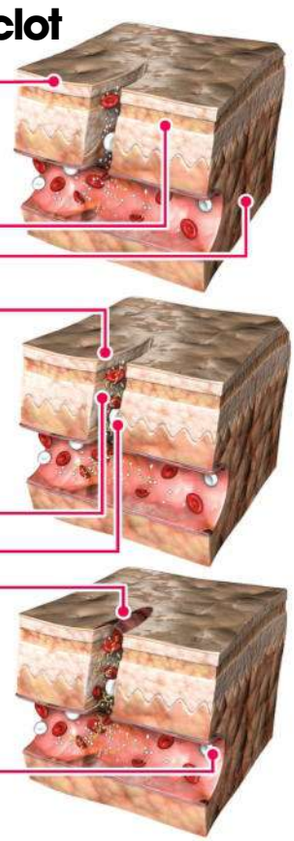
How to check your pulse

See whether you have a regular or irregular heart rate

Checking your pulse is a good way to track your heart rate. To get an accurate reading, monitor it while you're resting, as rhythm can change throughout the day, especially during exercise. You can check your radial pulse on your wrist or neck, because arteries pass close to the skin in these areas. For your wrist pulse, turn one hand over with the palm facing up. Place the index and middle finger from your other hand below the wrist crease, next to the tendon. Use gentle pressure and feel for a beating pulse. For the pulse in your neck, place the same two fingers below the jawline next to your windpipe. Find your pulse and use the second hand on a watch to count the number of beats per minute. A normal resting heart rate for an adult should be around 60 to 100 beats per minute.



Formation of a blood clot



Skin layer

Composed of a water- resistant and protective layer called the epidermis; beneath it is the dermis layer that consists of blood vessels and connective tissue.

Cut

If skin is cut, platelets in the blood vessels of the damaged area become 'sticky' and clump together at the damaged site to form a white clot. Other chemical reactions create sticky web-like strands of fibrin that adhere to the damaged blood vessel wall, to form a red clot.

Healing

The blood clot stops blood escaping from the wound, and allows the normal circulation of the red blood cells which transport oxygen around the body and the white blood cells that protect it against infection.

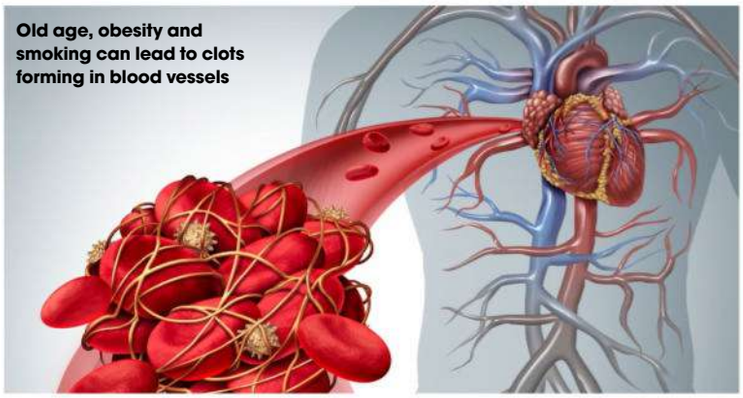
Blood clotting

How the body reacts to blood vessel damage to aid the healing process

Through the action of the thrombin system, coagulation of the blood occurs instantly at the location where there is a cut or other injury to the skin. The blood clot, which consists of a combination of cellular platelets and sticky strings of fibrin, forms a plug in the damaged blood vessels.

The clot stops blood from freely flowing out of the body and at the same time allows the blood to continue circulating. As the skin heals, plasmin enzymes break down the webs of fibrin and the clot is eventually dissolved into the body.

Clots can also form in blood vessels due to inactivity, old age, obesity, smoking, poor diet or during pregnancy. This condition is known as thrombosis and can lead to an embolism.



Old age, obesity and smoking can lead to clots forming in blood vessels

How the spleen works

Perhaps not as well known as famous organs like the heart, the spleen serves vital functions that help keep us healthy

The spleen's main functions are to remove old blood cells and fight off infection. Red blood cells have an average life span of 120 days. Most are created from the marrow of long bones, such as the femur. When they're old, it's the spleen's job to identify them, filter them out and then break them down. The smaller particles are then sent back into the bloodstream, and either recycled or excreted from other parts of the body. This takes place in the 'red pulp', which are blood vessel-rich areas of the spleen that make up about three-quarters of its structure.

The remainder is called 'white pulp', which are areas filled with different types of immune cell (such as lymphocytes). They filter out and destroy foreign pathogens, which have invaded the body and are circulating in the blood. The white pulp breaks them down into smaller, harmless particles.

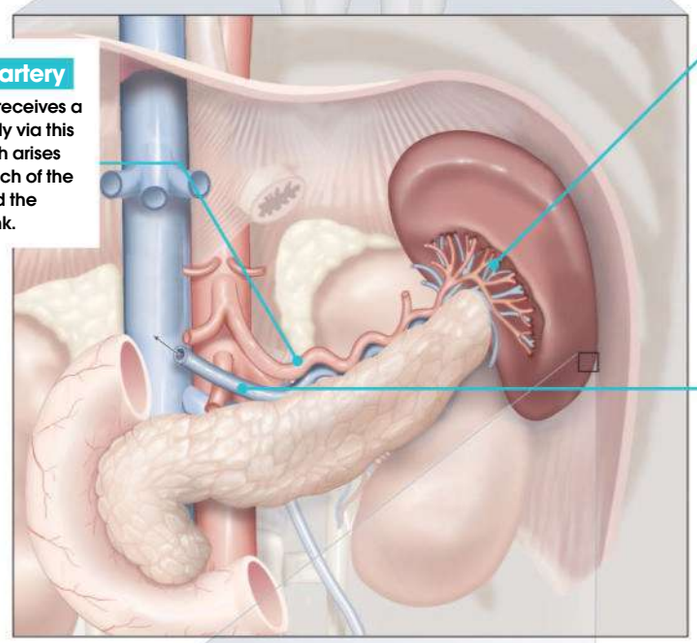
It is surrounded by a thin, fragile capsule and so is prone to injury. It sits beneath the lower ribs on the left-hand side of your body, which affords it some protection, but car crashes, major sports impacts and knife wounds can all rupture the organ. In the most serious cases, blood loss can endanger the person's life, and in these situations it needs to be removed by a surgeon. Since this reduces the body's ability to fight infections, some people will need to take antibiotics to boost their immunity for the rest of their lives.

"The spleen's main functions are to remove old blood cells and fight off infection"

Inside the spleen

We take you on a tour of the major features in this often-overlooked organ

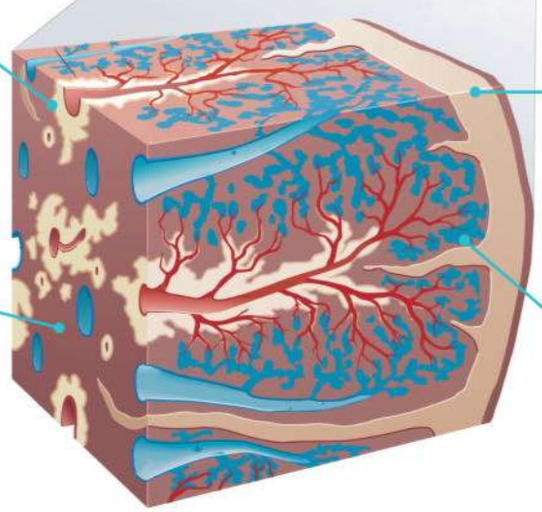
Location
The spleen sits underneath the 9th, 10th and 11th ribs (below the diaphragm) on the left-hand side of the body, which provides it with some protection against knocks.



Splenic artery
The spleen receives a blood supply via this artery, which arises from a branch of the aorta called the coeliac trunk.

Hilum
The entrance to the spleen, this is where the splenic artery divides into smaller branches and the splenic vein is formed from its tributaries.

Splenic vein
The waste products from filtration and pathogen digestion are returned to the main circulation via this vein for disposal.



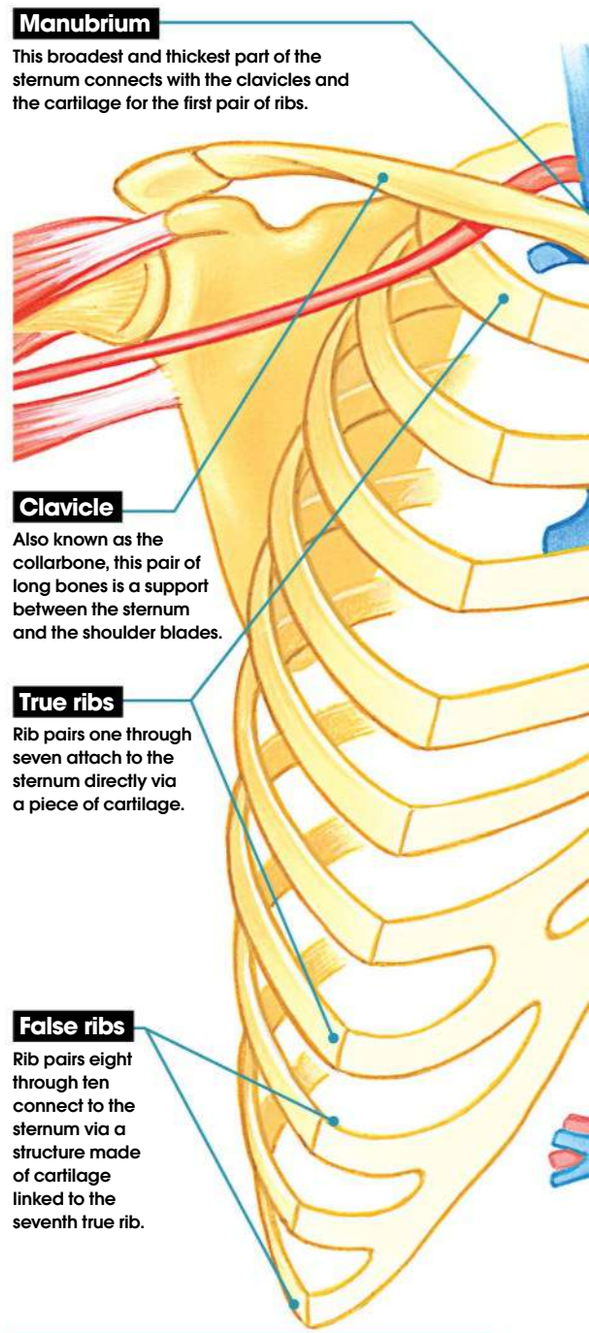
White pulp
Making up roughly a quarter of the spleen, the white pulp is where white blood cells identify and destroy any type of invading pathogens.

Red pulp
Forming approximately three-quarters of the spleen, the red pulp is where red blood cells are filtered and broken down.

Splenic capsule
The capsule provides some protection, but it's thin and relatively weak. Strong blows or knife wounds can easily rupture it and lead to life-threatening bleeding.

Sinusoid
Similar to those found in the liver, these capillaries allow for the easy passage of large cells into the splenic tissue for processing.

© Alamy



The human ribcage

Ribs are not merely armour for the organs inside our torsos, as we reveal here...

The ribcage – also known as the thoracic cage or thoracic basket – is easily thought of as just a framework protecting your lungs, heart and other major organs. Although that is one key function, the ribcage does so much more. It provides vital support as part of the skeleton and, simply put, breathing wouldn't actually be possible without it.

All this means that the ribcage has to be flexible. The conical structure isn't just a rigid system of bone – it's actually both bone and cartilage. The ribcage comprises 24 ribs, joining in the back to the 12 vertebrae making up the middle of the spinal column.

The cartilage portions of the ribs meet in the front at the long, flat three-bone plate called the sternum (breastbone). Or rather, most of them do. Rib pairs one through seven are called 'true ribs' because they attach directly to the sternum. Rib pairs eight through ten attach indirectly through other cartilage structures, so they're referred to as 'false ribs'. The final two pairs – the 'floating ribs' – hang unattached to the sternum.

Rib fractures are a common and very painful injury, with the middle ribs the most likely ones to get broken. A fractured rib can be very dangerous, because a sharp piece could pierce the heart or lungs.

There's also a condition called flail chest, in which several ribs break and then detach from the cage, which can even be fatal. But otherwise there's not much you can do to mend a fractured rib other than keep it stabilised, resting and giving it time to heal.

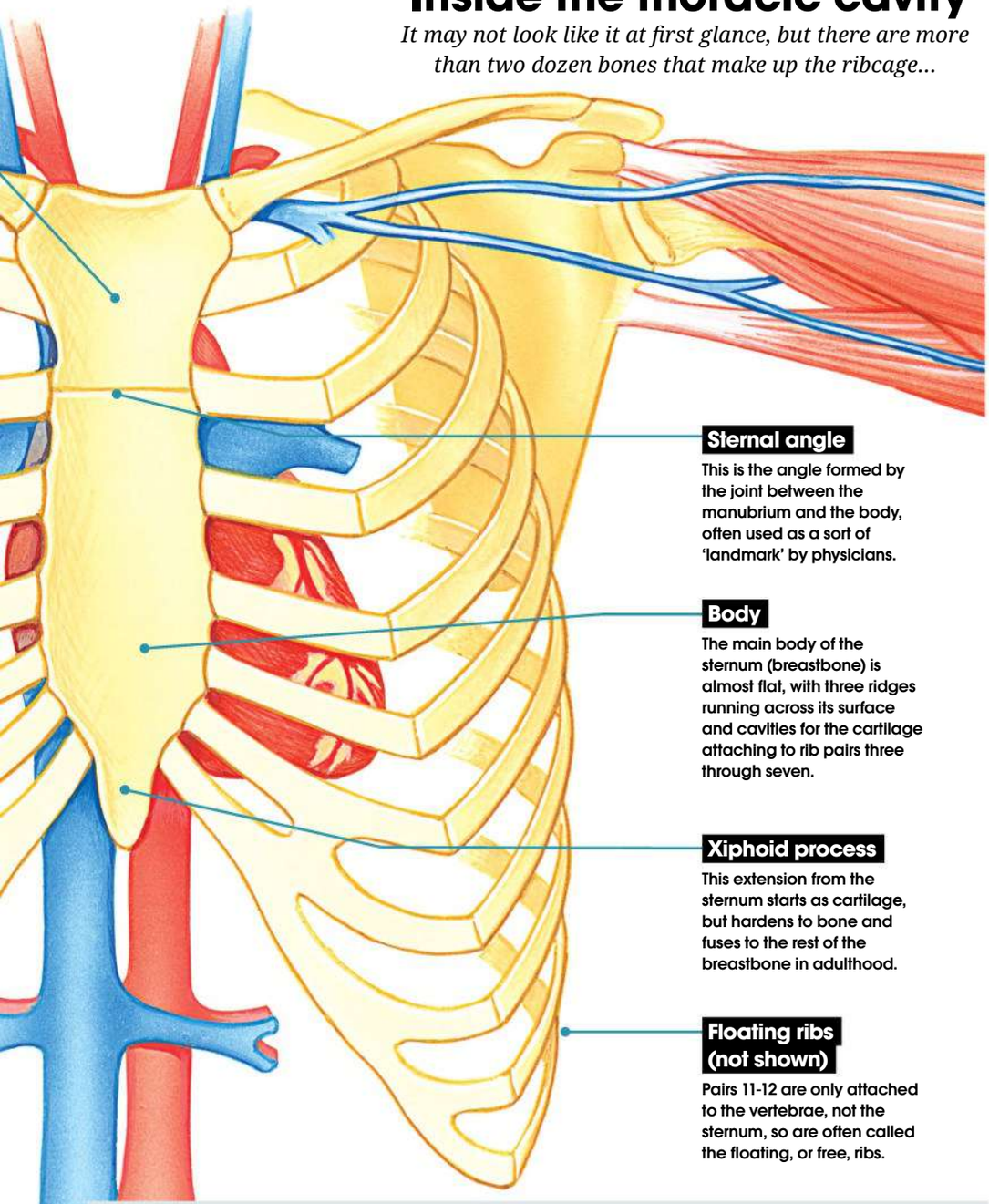
What are hiccups?

Hiccupping – known medically as singultus, or synchronous diaphragmatic flutter (SDF) – is an involuntary spasm of the diaphragm that can happen for a number of reasons. Short-term causes include eating or drinking too quickly, a sudden change in body temperature or shock.

However, some researchers have suggested that hiccupping in premature babies – who tend to hiccup much more than full-term babies – is due to their underdeveloped lungs. It could be an evolutionary leftover, since hiccupping in humans is similar to the way that amphibians gulp water and air into their gills to breathe.

Inside the thoracic cavity

It may not look like it at first glance, but there are more than two dozen bones that make up the ribcage...



Sternal angle

This is the angle formed by the joint between the manubrium and the body, often used as a sort of 'landmark' by physicians.

Body

The main body of the sternum (breastbone) is almost flat, with three ridges running across its surface and cavities for the cartilage attaching to rib pairs three through seven.

Xiphoid process

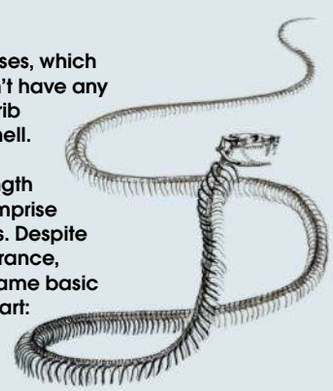
This extension from the sternum starts as cartilage, but hardens to bone and fuses to the rest of the breastbone in adulthood.

Floating ribs (not shown)

Pairs 11-12 are only attached to the vertebrae, not the sternum, so are often called the floating, or free, ribs.

Ribs in other animals

Most vertebrates (animals with backbones) have a ribcage of sorts – however, ribcages can be very different depending on the creature. For example, dogs and cats have 13 pairs of ribs as opposed to our 12. Marsupials have fewer ribs than humans, and some of those are so tiny they aren't much more than knobs of bone sticking out from the vertebrae. Once you get into other vertebrates, the differences are even greater. Birds' ribs overlap one another with hook-like structures called uncinate processes, which add strength. Frogs don't have any ribs, while turtles' eight rib pairs are fused to the shell. A snake's 'ribcage', meanwhile, runs the length of its body and can comprise hundreds of pairs of ribs. Despite the variations in appearance, ribcages all serve the same basic functions for the most part: to provide support and protection to the rest of the body.



Breathe in, breathe out...

Take in a breath and think about the ten different muscle groups that are working together to make it happen. The intercostal muscles, which are attached to the ribs and run between them, move the ribcage. As you inhale, the external intercostals raise the ribs and sternum so your lungs can expand, while your diaphragm lowers and flattens. The internal intercostals lower the ribcage when you exhale. This forces the lungs to compress and release air. If you breathe out gently, it's a passive process that doesn't require much ribcage movement.

Inhalation

As you inhale, the intercostal muscles contract to expand and lift the ribcage.

Contraction

The diaphragm contracts by moving downward, allowing the lungs to fill with air.

Exhalation

The intercostal muscles relax as we exhale, compressing and lowering the ribcage.

Relaxation

The diaphragm relaxes, moving upward to force air out of the lungs.

© Thinkstock

Human respiration

Respiration is crucial to an organism's survival. It is the transportation of oxygen from the air into our body's tissue cells so that energy can be broken down

The primary organs used for respiration in humans are the lungs. Humans have two lungs, with the left lung being divided into two lobes and the right into three. Lungs have between 300–500 million alveoli, which is actually where gas exchange occurs.

Respiration of oxygen breaks into four main stages: ventilation, pulmonary gas exchange, gas transportation and peripheral gas exchange. Each stage is crucial in getting oxygen to the body's tissue, and removing carbon dioxide. Ventilation and gas transportation need energy to occur, as the diaphragm and the heart are used to facilitate these actions, whereas gas exchanging is passive. Air is drawn into the lungs at a rate of between 10-20 breaths per minute while resting, through either your mouth or nose by diaphragm contraction, and travels through the pharynx, then the larynx, down the trachea, and into one of the two main bronchial tubes. Mucus and cilia keep the lungs clean by catching dirt particles and sweeping them up the trachea.

When air reaches the lungs, oxygen is diffused into the bloodstream through the alveoli and carbon dioxide is diffused from the blood into the lungs to be exhaled. Diffusion of gases occurs because of differing pressures in the lungs and blood. This is also the same when oxygen diffuses into tissue around the body. When blood has been oxygenated by the lungs, it is transferred around the body to where it is most needed in the bloodstream. If the body is exercising, the breathing rate increases and, consequently, so does the heart rate to ensure that oxygen reaches tissues that need it. Oxygen is then used to break down glucose to provide energy for the body. This happens in the mitochondria of cells. Carbon dioxide is one of the waste products of this, which is why we get a build up of this gas in our body that needs to be transported back into the lungs to then be exhaled.

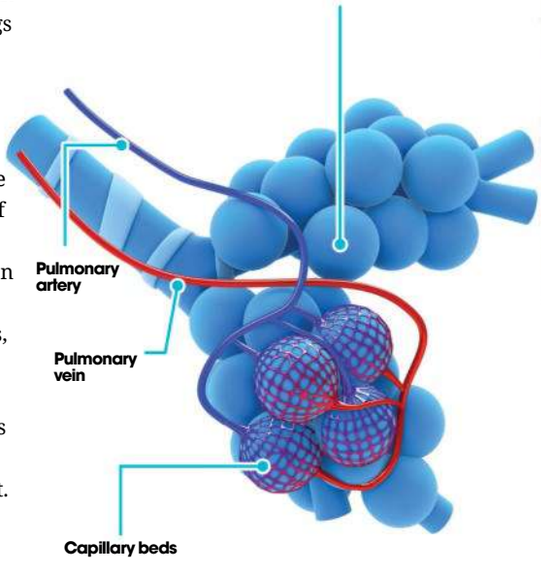
The body can also respire anaerobically, but this produces far less energy and instead of producing CO2 as a by-product, lactic acid is produced. The body then takes time to break this down after exertion has finished as the body has a so-called oxygen debt.

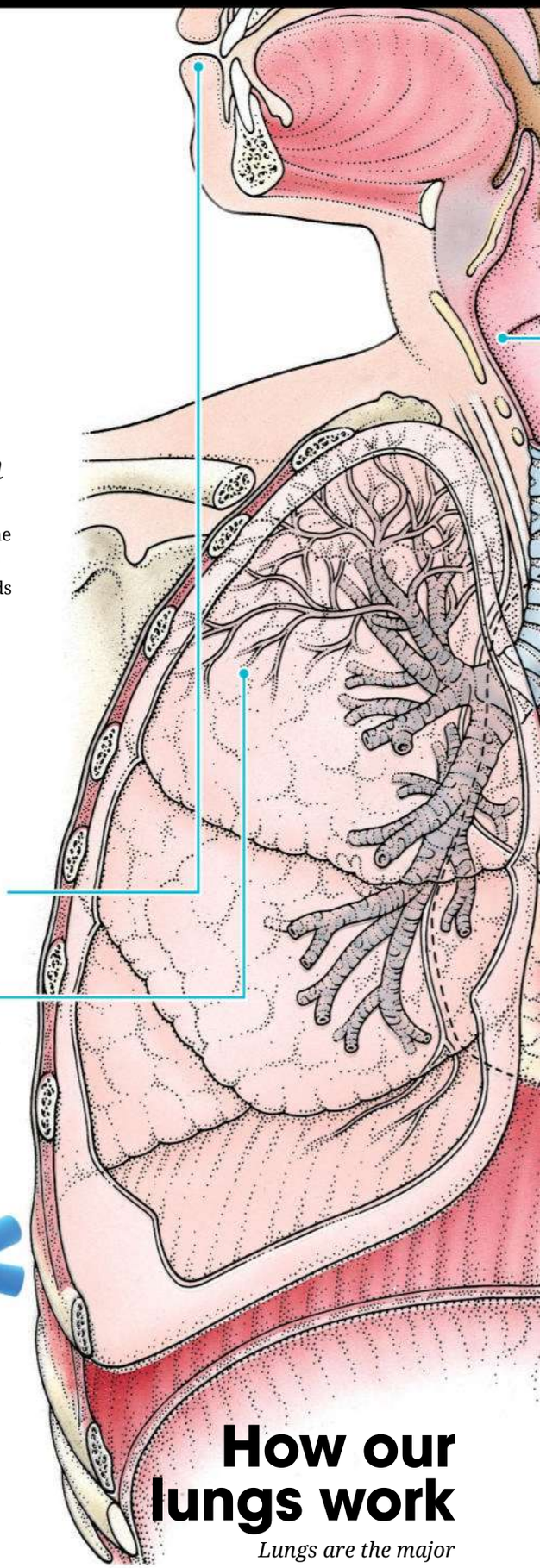
Nasal passage/oral cavity

These areas are where air enters into the body so that oxygen can be transported into and around the body to where it's needed. Carbon dioxide also exits through these areas.

Alveoli

The alveoli are tiny little sacs that are situated at the end of tubes inside the lungs and are in direct contact with blood. Oxygen and carbon dioxide transfer to and from the blood stream through the alveoli.





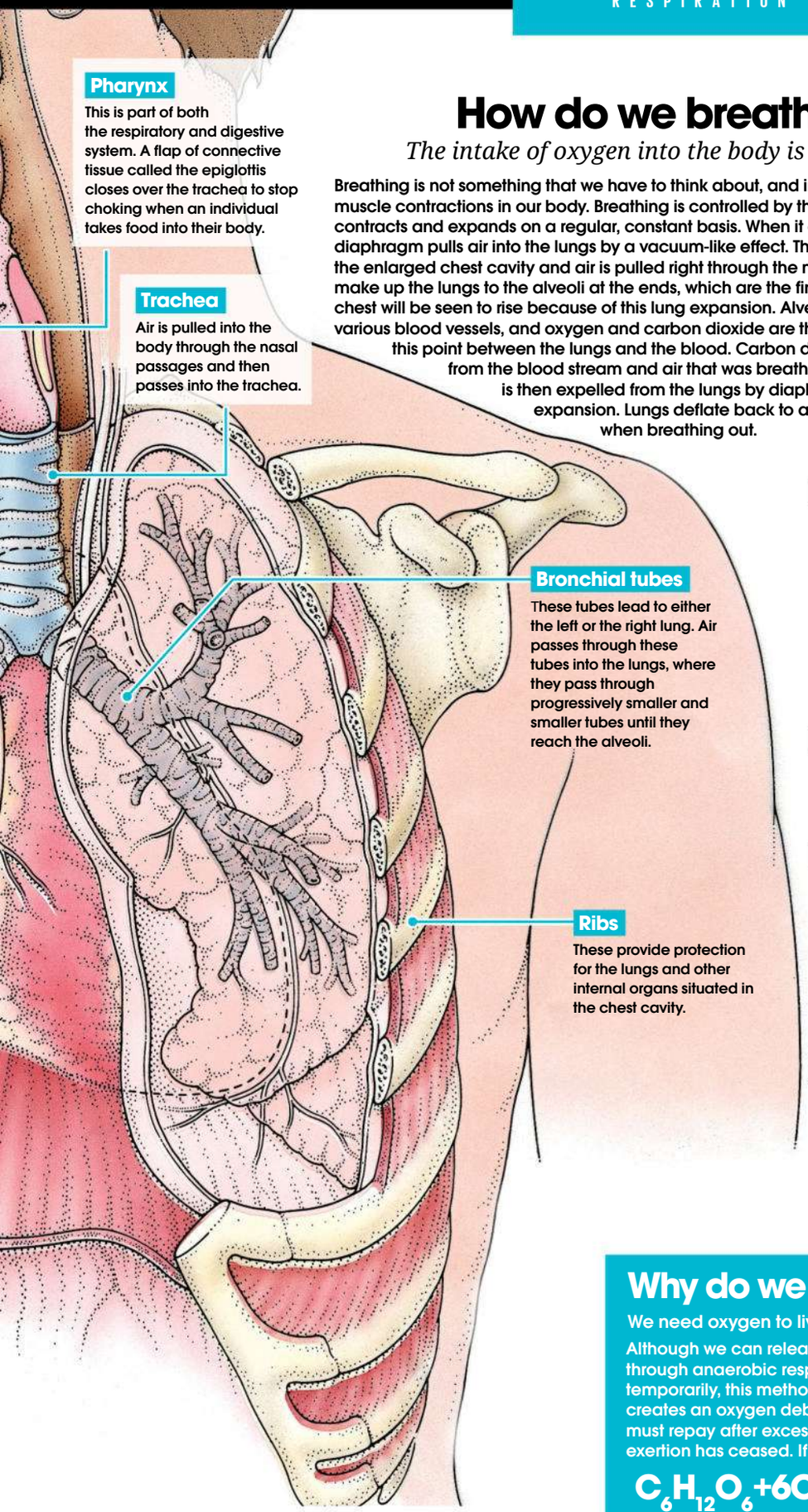
How our lungs work

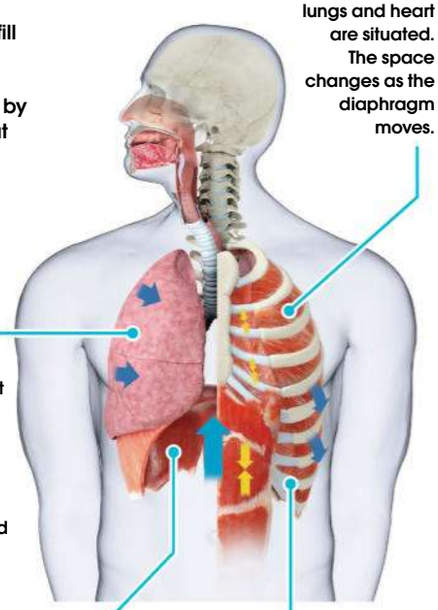
Lungs are the major respiratory organ in humans

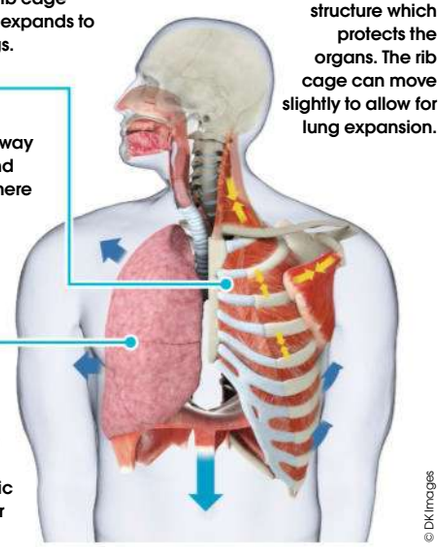
How do we breathe?

The intake of oxygen into the body is complex

Breathing is not something that we have to think about, and indeed is controlled by muscle contractions in our body. Breathing is controlled by the diaphragm, which contracts and expands on a regular, constant basis. When it contracts, the diaphragm pulls air into the lungs by a vacuum-like effect. The lungs expand to fill the enlarged chest cavity and air is pulled right through the maze of tubes that make up the lungs to the alveoli at the ends, which are the final branching. The chest will be seen to rise because of this lung expansion. Alveoli are surrounded by various blood vessels, and oxygen and carbon dioxide are then interchanged at this point between the lungs and the blood. Carbon dioxide removed from the blood stream and air that was breathed in but not used is then expelled from the lungs by diaphragm expansion. Lungs deflate back to a reduced size when breathing out.







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Why do we need oxygen?

We need oxygen to live as it is crucial for the release of energy within the body

Although we can release our energy through anaerobic respiration temporarily, this method is inefficient and creates an oxygen debt that the body must repay after excess exercise or exertion has ceased. If oxygen supply is cut off for more than a few minutes, an individual will die. Oxygen is pumped around the body to be used in cells that need to break down glucose so that energy is provided for the tissue. The equation that illustrates this is:

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + \text{energy}$$

Food & your body

Join us as we unravel all nine metres of your digestive system

The digestive tract is a long, muscular tube that runs the entire length of your body. It's separated into five distinct sections, each with its own function.

Digestion begins in the mouth. As you chew your food, saliva is released, providing a lubricant and kick-starting the breakdown of carbohydrates with the enzyme amylase. Touch receptors in your mouth tell you when to swallow, and as your tongue comes up, the food is pushed to the back of your throat.

As you swallow, you pass control of digestion over to your automatic motor functions. A flap of skin called the epiglottis folds down to cover the voice box, and the entrance to the lungs, and then a wave pushes the mouthful all the way down the oesophagus. When the food reaches your stomach, it passes through a ring of muscle known as the cardiac sphincter, which prevents it from coming back out the way it came in.

The inside of the stomach is a hostile environment, where the cells lining the walls pump out hydrochloric acid and protein-digesting enzymes. The presence of food triggers stretch receptors in the stomach lining, which in turn trigger a series of rhythmic contractions. These churn the stomach contents, mixing in the acid and enzymes, grinding down the food.

At the bottom of the stomach there is a second ring of muscle called the pyloric sphincter, which acts as a gatekeeper to the small intestine. The sphincter prevents anything larger than about two centimetres (0.8 inches) in diameter passing, returning it to the body of the stomach until it's been ground

further. This ensures that by the time it reaches the small intestine, your food is a runny, slightly lumpy paste, ready for the next stage.

The small intestine is the site of chemical digestion. Here, the pancreas adds digestive enzymes, and the liver adds a generous squirt of alkaline bile, delivered via the gall bladder. This bile not only neutralises the burning stomach acid, it also acts a little like washing-up liquid on dirty dinner dishes, helping to separate the food particles and forcing fats to disperse into tiny bubbles.

Muscles in the small intestine continue to squeeze and mix the contents together, allowing the enzymes to get to work inside the paste. As the nutrients are released, they are then absorbed over the walls of the intestine and into the bloodstream.

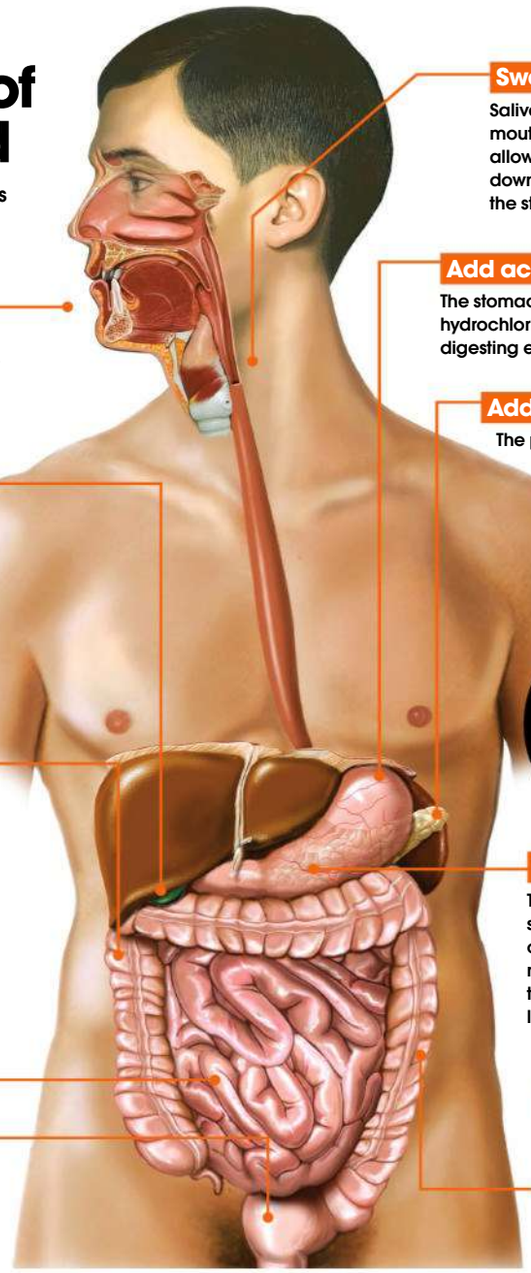
To ensure that everything keeps moving through the system, every five to ten minutes a wave of muscle contractions begins at the stomach and travels all the way down the intestines. Known as the migrating motor complex (MMC), this wave squeezes the digestive system like a tube of toothpaste, urging its contents further toward the colon.

As the food progresses through the system to the small intestine, more and more of the nutrients are released by enzyme activity, and by the time it reaches the large intestine, most useful material has been absorbed into the bloodstream. However, the digestive process is not yet over, and here, bacteria help break down even more of what's left.

The large intestine also absorbs most of the remaining water, leaving a combination of undigested material, dead cells and bacteria. The waste then goes to the rectum for storage until there is a convenient time to get rid of it.

Journey of your food

It can take up to 48 hours for a meal to travel through your body



Chew
Digestion begins in the mouth, where our teeth start work on grinding food into manageable chunks.

Swallow
Saliva makes each mouthful slippery, allowing it to slide easily down the oesophagus to the stomach.

Add acid and enzymes
The stomach produces hydrochloric acid, and protein-digesting enzymes.

Add more enzymes
The pancreas produces digestive enzymes, which are added to the mixture as it enters the small intestine.

Add bile
As the liquid passes into the intestines, stomach acid is neutralised by alkaline bile from the liver.

7 metres
Length of the small intestine

Ferment waste
Bacteria living in the large intestine help with the breakdown of waste, releasing even more nutrients.

Churn
The muscles of the stomach rhythmically churn its contents, mechanically breaking the food down into a lumpy paste.

Absorb nutrients
As the enzymes begin to release nutrients, they're absorbed across the lining of the small intestine into the bloodstream.

Remove water
The large intestine absorbs excess water from the food as it passes through.

Get rid of waste
All that's left at the end of the digestive process is a combination of indigestible material, dead cells and bacteria.

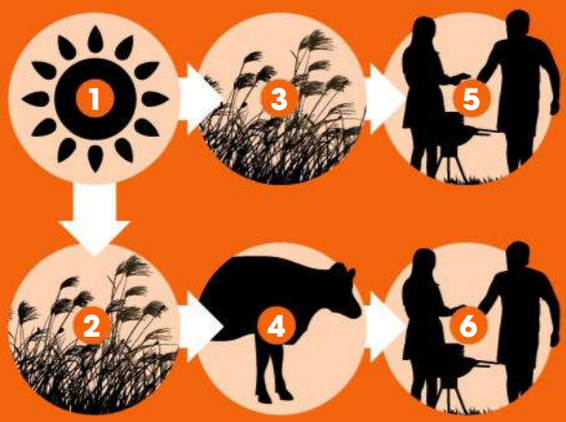
Food chain

Energy from the sun is converted into chemical energy by photosynthetic organisms like plants. The plants use the energy to build biological materials from nutrients in the air and soil. Herbivores then consume the plants, releasing some of the energy, and using the components to build their own bodies. Carnivores then eat the herbivores. When plants and animals die, decomposers break their bodies down, returning nutrients to the ground for reuse, and the cycle begins again.

1 The sun
On average, every minute the sun delivers 2kcal of energy for every cm2 (0.2in2) of Earth.

2 Inefficient conversion
Less than five per cent of the available energy from the sun is converted into chemical energy by plants.

3 Producer
Plants use the energy from the sun to combine CO_2 and water, producing chemical energy in the form of sugars.



4 Herbivore
Herbivores can digest plant material, but the process is difficult, and they can only extract around ten per cent of the energy.

5 Energy loss
At every step up in the food chain, some of the energy is lost, mostly as heat.

6 Carnivore
Carnivores get easy energy by digesting the tissues of other animals.

Sense of taste

Taste tells us whether our food is safe to eat, but smell gives it flavour

The human tongue is able to detect five different tastes: sweet, sour, salty, bitter and umami (savoury), providing us with a quick way to distinguish between different types of food. Sweet foods contain sugar and are a good source of energy. Salty foods provide sodium, which is vital for nerve function, but deadly in high quantities. Bitter foods might contain poison.

Babies have a natural preference for sweet food and a dislike of anything bitter, a biological safeguard that encourages them to eat safe, high-calorie food. But nutrition is not so simple. Many vegetables are bitter but not poisonous; learning to like them takes experience.

The degree to which we can detect different tastes varies, and appears to be dictated by our individual anatomy. The population can be broadly divided into three categories based on the number of taste buds on their tongue. Those with the fewest are known as 'non-tasters', those with an average number are known as 'tasters', and those with many more taste buds than the rest of the population are 'supertasters.' Supertasters are especially sensitive to taste and will react much more strongly than the rest of the population. As a result, they tend to really dislike bitter foods like green vegetables and coffee, and often shy away from rich desserts and sugary sweets.

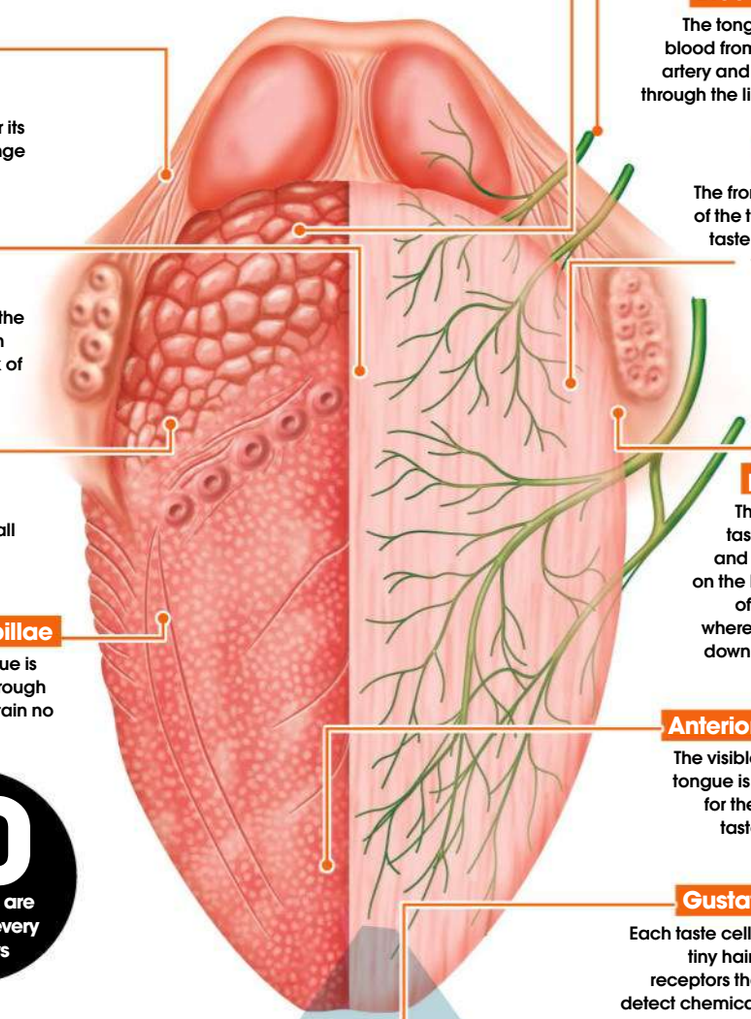
Though these anatomical differences can explain some of our food preferences, most of our individual likes and dislikes are not down to taste, but to flavour; the combination of taste and smell.

The act of chewing food releases chemicals known as volatiles, which evaporate rapidly. As we swallow, some of the air inside the mouth is forced up toward the nose, carrying these volatiles with it. Here, they bind to receptors on olfactory cells, triggering sensory messages to the brain.

Recently, scientists have found that these olfactory receptors can detect as many as 1 trillion different odours. Taste and smell are strongly linked to emotion and memory, and as a result, experience is a powerful decider in the development of our likes and dislikes.

Anatomy of a human tongue

Contrary to popular belief, all five tastes can be detected almost anywhere on the tongue



Circumvallate papillae
These large bumps are found at the back of the tongue, each surrounded by a dip that collects saliva.

Blood supply
The tongue receives blood from the lingual artery and it drains out through the lingual veins.

Nerves
The front and back of the tongue send taste information to the brain.

Muscle
There are eight muscles in the tongue that alter its shape and change its position.

Posterior tongue
About a third of the tongue is hidden right at the back of the mouth.

Papillae
The tongue is covered in tiny bumps, but not all of them contain taste buds.

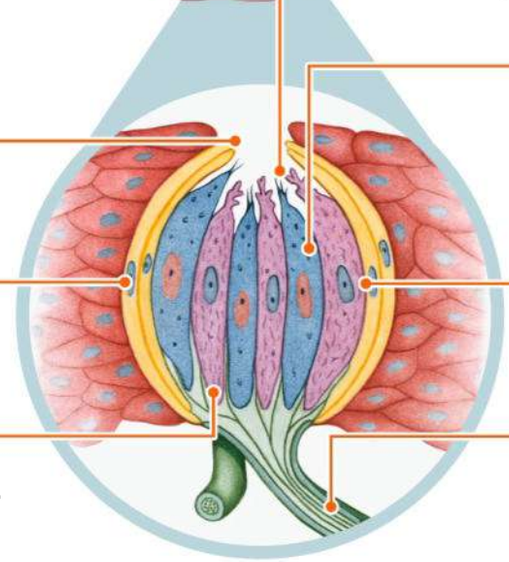
Filiform papillae
Most of the tongue is covered in thin, rough bumps that contain no taste receptors.

Foliate papillae
These contain taste receptors and are located on the back edges of the tongue, where saliva drips down the cheeks.

Anterior tongue
The visible part of the tongue is responsible for the majority of taste detection.

10
Taste cells are replaced every ten days

What is a taste bud?



Gustatory hair
Each taste cell ends with a tiny hair, covered in receptors that allow it to detect chemicals dissolved in the saliva.

Basal cell
Ageing or damaged taste cells are replaced by the basal cells waiting underneath.

Pore
A tiny gap at the top of the taste bud allows saliva to touch the taste cells.

Support cell
The taste cells are surrounded by an envelope of non-tasting support cells.

Sensory cell
Each cell is sensitive to one of the five tastes, but all types are found together in a single taste bud.

Synapse
Taste cells do not transmit the signals to the brain themselves, instead passing the message over to a nerve cell.

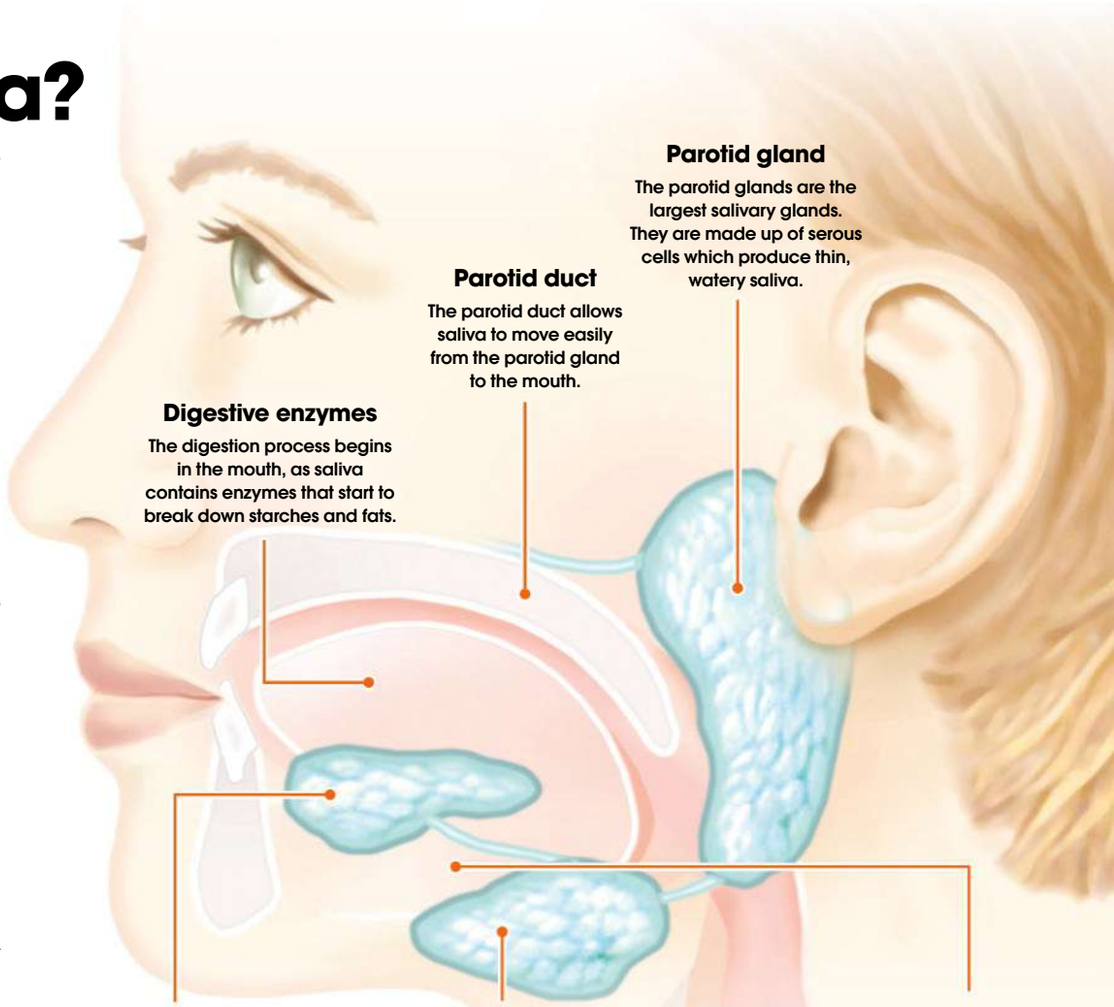
Nerve
Messages are relayed to the brain via a nerve that exits at the bottom of the taste bud.

What is saliva?

Find out this frothy liquid's vital role in maintaining human health

Humans can produce an incredible two litres of saliva each day. It is made up of 99.5 per cent water, so how is it able to perform so many important functions? Well, the remaining 0.5 per cent contains a host of enzymes, proteins, minerals and bacterial compounds. As soon as food enters the mouth, saliva's enzymes start to break it into simpler components, while also lubricating even the driest snack to slide easily down. Saliva also helps protect teeth from decay and controls bacterial levels in the mouth to help reduce the overall risk of infection. Without sufficient saliva, tongue and lip movements are not as smooth, which, in extreme cases, can make it very difficult to speak.

Saliva can reveal a great deal. New studies have shown that a saliva test can be used to find out whether a person is at risk of a heart attack, as it contains C-reactive protein (CRP). This can be an indicator of heart disease when found at elevated levels in the blood. A saliva test is much less intrusive than a blood test and gives doctors a rough estimate of the health of a patient's heart. What's more, saliva contains your entire genetic blueprint. Even less than half a teardrop can provide a workable DNA sample that can be frozen and thawed without breaking down.



How long does it take to digest food?

The sight, smell and even the thought of food begin to prepare the stomach for a meal, so by the time the swallowed mouthfuls start to arrive, it is already producing more acid.

Stretching and irritation of the stomach trigger it to turn up acid and enzyme production and to start churning. For the first 20 to 30 minutes after eating a meal, no food is allowed to leave.

To stop the stomach emptying too quickly, protein and fat are monitored in the first part of the small intestine. If too much food comes through, the intestine sends signals to slow the stomach down.

Chewing the fat

Fat has a bad reputation, but the truth is, your body needs it

Every single cell in your body is surrounded by a membrane made of fats; it insulates your nerves and it provides a valuable energy reserve. Eating fat also provides a number of vitamins and essential fatty acids the body can't make on its own. Saturated fats (the solid fats found in meat and dairy) and trans fats (found in hydrogenated vegetable oil and many processed foods) have shown to raise cholesterol, which can lead to circulatory problems, but unsaturated fats (the liquid fats found in plants and fish) can have the opposite effect, and are considered good for your health.

Inside the stomach

Discover how this amazing digestive organ stretches, churns and holds corrosive acid to break down our food, all without getting damaged

The stomach's major role is as a reservoir for food; it allows large meals to be consumed in one go before being gradually emptied into the small intestine. A combination of acid, protein-digesting enzymes and vigorous churning action breaks the stomach contents down into an easier-to-process liquid form, preparing food for absorption in the bowels.

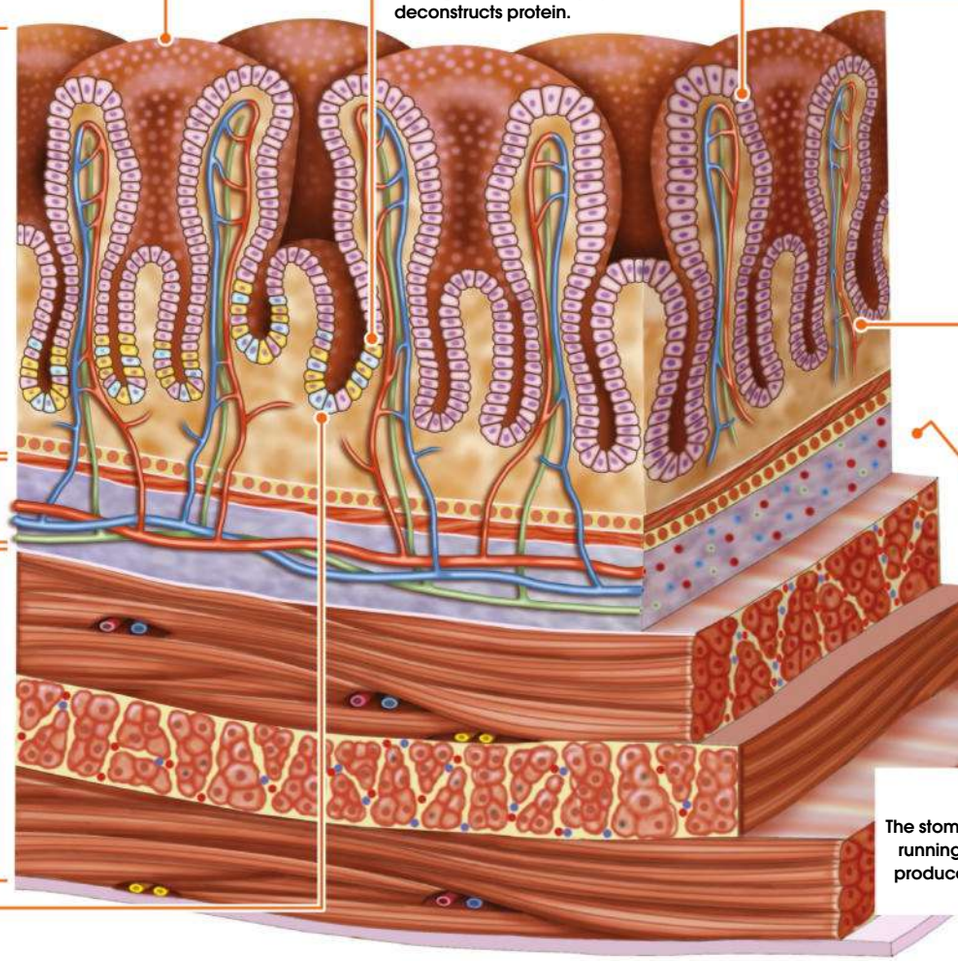
In resting state, the stomach contracts and the internal surface of the organ folds into ridges, or rugae. When we start eating, however, the stomach begins to distend; the rugae flatten, allowing the stomach to expand, and the outer muscles relax. It can accommodate about a litre of food without discomfort.

The expansion of the stomach activates stretch receptors, which trigger nerve signalling that results in increased acid production and powerful muscle contractions to churn the contents. Gastric acid causes proteins in the food to unravel, allowing access by the enzyme pepsin, which breaks down protein. The partially digested proteins stimulates enteroendocrine cells (G-cells) to make the hormone gastrin, and even more acid.

The stomach empties into the small intestine through the pyloric sphincter. Liquids pass through the sphincter easily, but solids must be narrower than one to two millimetres before they fit. Anything larger is 'refluxed' back into the main chamber for further breakdown. It takes about two hours for half a meal to pass into the small intestine and the process is generally done within four to five hours.

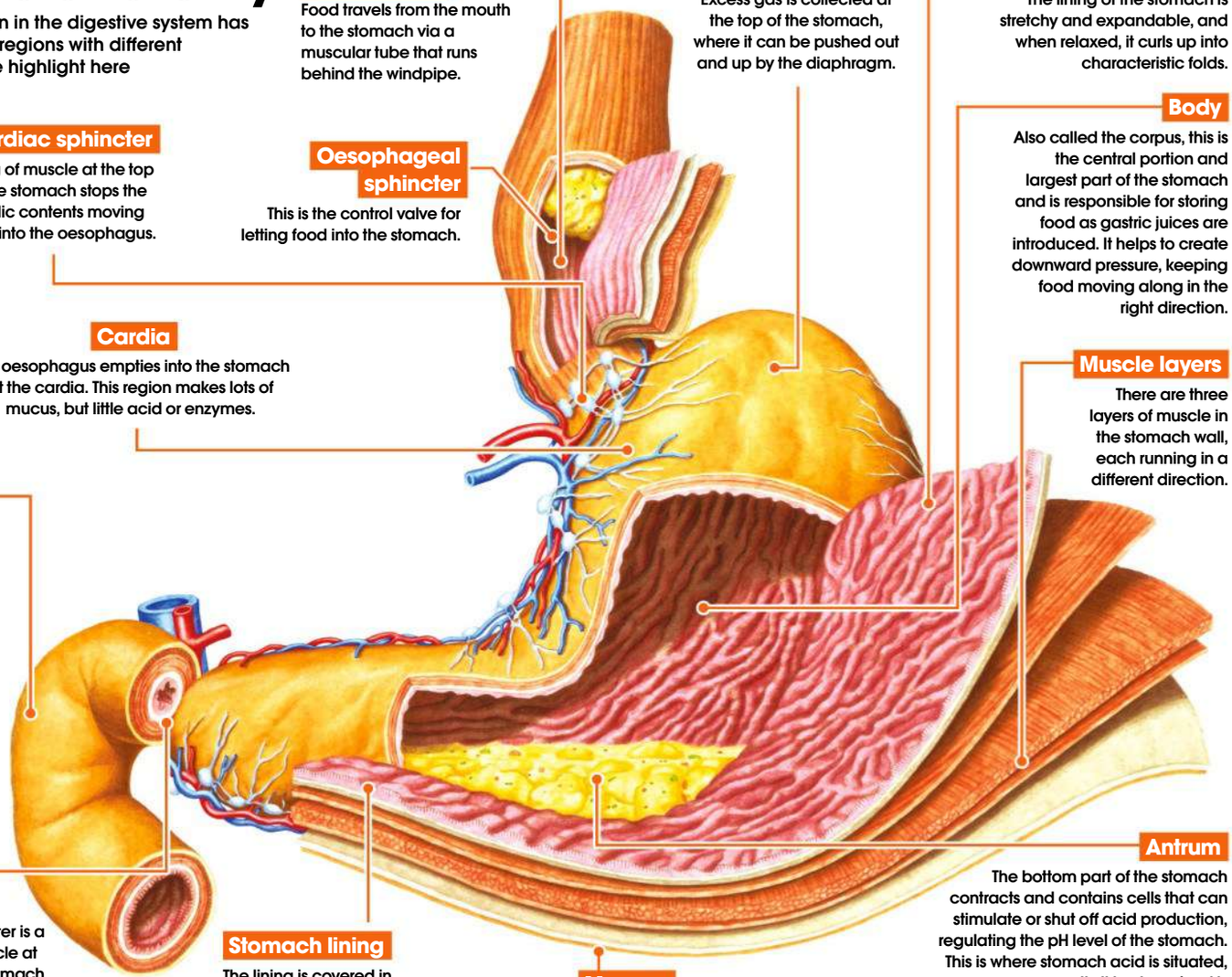
Lining under the microscope

The stomach is much more than just a storage bag. Take a look at its complex microanatomy now...



Gastric anatomy

This major organ in the digestive system has several distinct regions with different functions, as we highlight here



Oesophagus
Food travels from the mouth to the stomach via a muscular tube that runs behind the windpipe.

Fundus
Excess gas is collected at the top of the stomach, where it can be pushed out and up by the diaphragm.

Rugae
The lining of the stomach is stretchy and expandable, and when relaxed, it curls up into characteristic folds.

Cardiac sphincter
A ring of muscle at the top of the stomach stops the acidic contents moving back into the oesophagus.

Oesophageal sphincter
This is the control valve for letting food into the stomach.

Body
Also called the corpus, this is the central portion and largest part of the stomach and is responsible for storing food as gastric juices are introduced. It helps to create downward pressure, keeping food moving along in the right direction.

Cardia
The oesophagus empties into the stomach at the cardia. This region makes lots of mucus, but little acid or enzymes.

Muscle layers
There are three layers of muscle in the stomach wall, each running in a different direction.

Duodenum
The stomach empties its contents into the first section of the small intestine.

Antrum
The bottom part of the stomach contracts and contains cells that can stimulate or shut off acid production, regulating the pH level of the stomach. This is where stomach acid is situated, consequently it is where food is broken down into molecules that the small intestine can then process.

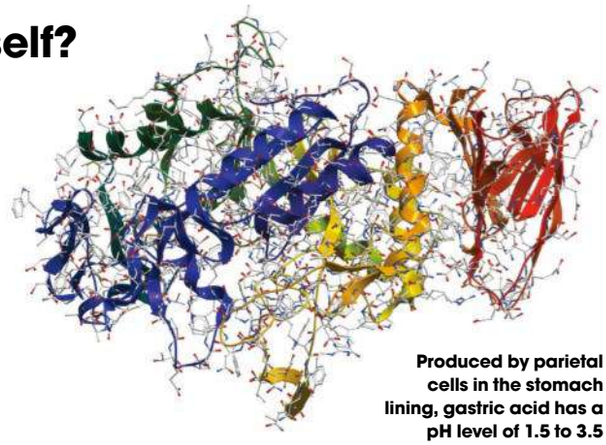
Pyloric sphincter
The pyloric sphincter is a strong ring of muscle at the base of the stomach that regulates the passage of food from the stomach to the bowels.

Stomach lining
The lining is covered in microscopic pits that produce mucus, acid and protein-digesting enzymes.

Mucosa
These cells line all of the stomach to aid movement of food throughout the organ.

Why doesn't it digest itself?

Your stomach is full of corrosive acid and enzymes capable of breaking down protein – if left unprotected the stomach lining would quickly be destroyed. To prevent this from occurring, the cells lining the stomach wall produce carbohydrate-rich mucus, which forms a slippery, gel-like barrier. The mucus contains bicarbonate, which is alkaline and buffers the pH at the surface of the stomach lining, preventing damage by acid. For added protection, the protein-digesting enzyme pepsin is created from a zymogen (the enzyme in its inactive form) – pepsinogen; it only becomes active when it comes into contact with acid, a safe distance away from the cells that manufacture it.



Produced by parietal cells in the stomach lining, gastric acid has a pH level of 1.5 to 3.5

Vomit reflex step-by-step

Vomiting is the forceful expulsion of the stomach contents up the oesophagus and out of the mouth. It's the result of three co-ordinated stages. First, a deep breath is drawn and the body closes the glottis, covering the entrance to the lungs. The diaphragm then contracts, lowering pressure in the thorax to open up the oesophagus. At the same time, the muscles of the abdominal wall contract, which squeezes the stomach. The combined shifts in pressure both inside and outside the stomach forces any contents upwards.

The intestines

After leaving the stomach, food must pass through over 7m (23ft) of intestines

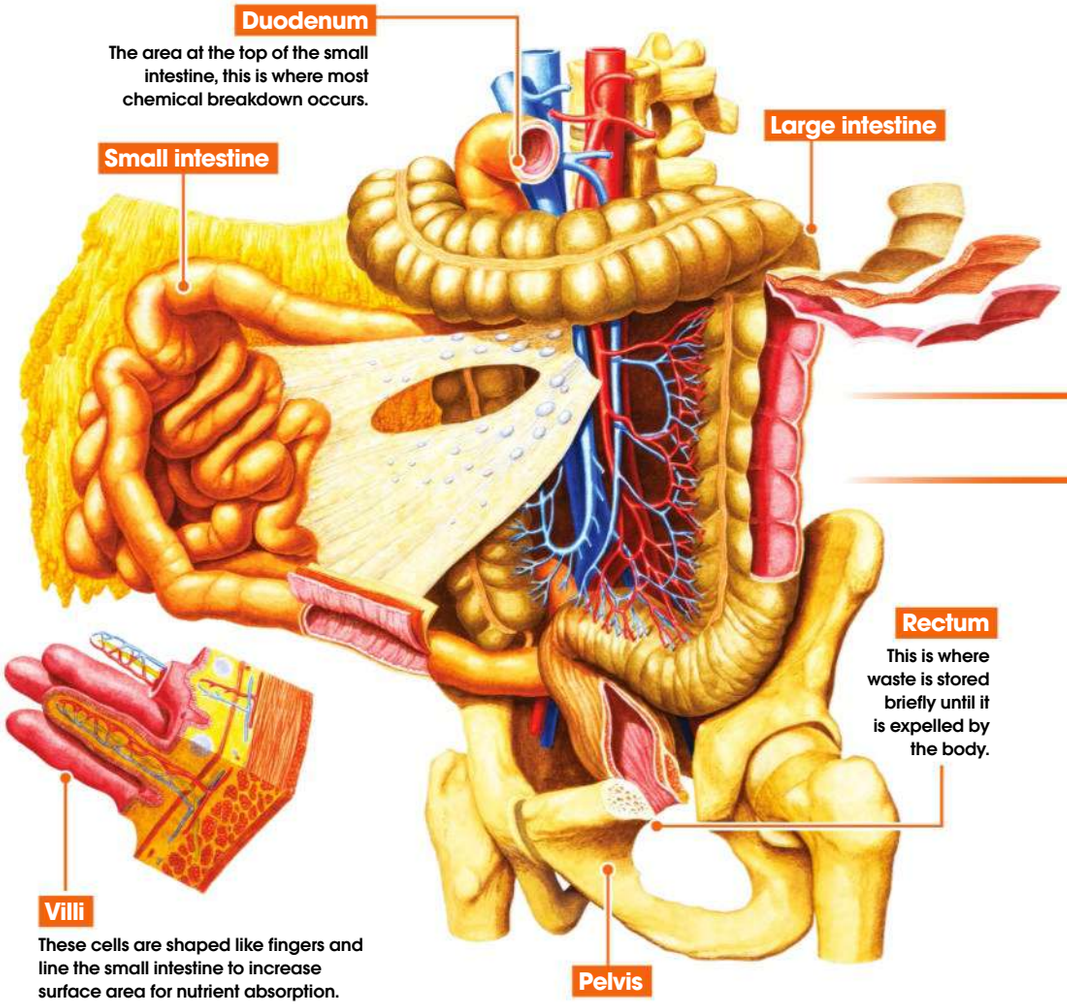
The intestine splits into two distinct parts, the small intestine and the large intestine. The small intestine is where the food goes through final stages of digestion and nutrients are absorbed into the blood stream, the large intestine is where waste is stored until it's ultimately expelled through the anus. Both the small and large intestines can be further divided into sections, the duodenum, jejunum and ileum are the three distinct sections of the small intestine and the cecum, colon and rectum are the sections of the large intestine. As well as storing waste, the large intestine removes water and salt from the waste before it is expelled. Muscle contractions and mucosa are essential for the intestine to work properly, and we see a variation of mucosa, called villi, present in the lower intestine.

The first part of the digestive system prepares the food for the next stage, ensuring it is broken into a fine paste, mixed to form a homogenous fluid, and shocked with acid to limit the potential for dangerous infection. However, it is not until food reaches the small intestine that the microscopic breakdown and absorption of nutrients really begins.

The stomach contents enter the intestine gradually, allowing time for the liquid food to be processed. First the acid is neutralised by bile, provided by the liver, and then digestive enzymes are added by the pancreas. The enzymes act like molecular scissors, breaking proteins, carbohydrates and fats down into building blocks small enough to be carried over the wall of the small intestine. The remaining undigested material passes into the large intestine, which absorbs water, leaving behind solid waste that can then be passed out of the body.

At the start of the small intestine, the liver injects alkaline bile into the acidic liquid food, neutralising its pH and preparing it for the introduction of digestive enzymes.

Bile also helps emulsify fats. Fats are not water soluble, so they tend to clump in large globules to avoid the surrounding water, but bile acts a little like washing-up liquid, separating the fats out into smaller blobs.



Now that the food is nicely mixed and separated, the enzymes can get to work. The pancreas produces a cocktail of three kinds of enzyme, each used to break down a different type of molecule. Proteases clip amino acids from proteins, lipases break fats down into fatty acids and glycerol, and carbohydrases turn long chains of carbohydrate into sugars. These small blocks can be absorbed into the bloodstream, where they're distributed around the body, used to build our own biological molecules, or broken down and burnt for energy. The body requires different quantities of each of the nutrients, and can sometimes convert one into another if supplies are running low. However, there are a number of nutrients that cannot be synthesised by the body at all or in high enough quantities, and these must be obtained directly from the diet. These essential nutrients include some types of amino acids, fatty acids like omega-3 and omega-6, and all of the vitamins and minerals needed.

Vitamins and minerals are organic and inorganic compounds required by the body in small amounts for various different functions. Some of these, like calcium, make up vital structural components of our bodies, while others, like vitamin C, are involved in biochemical reactions.

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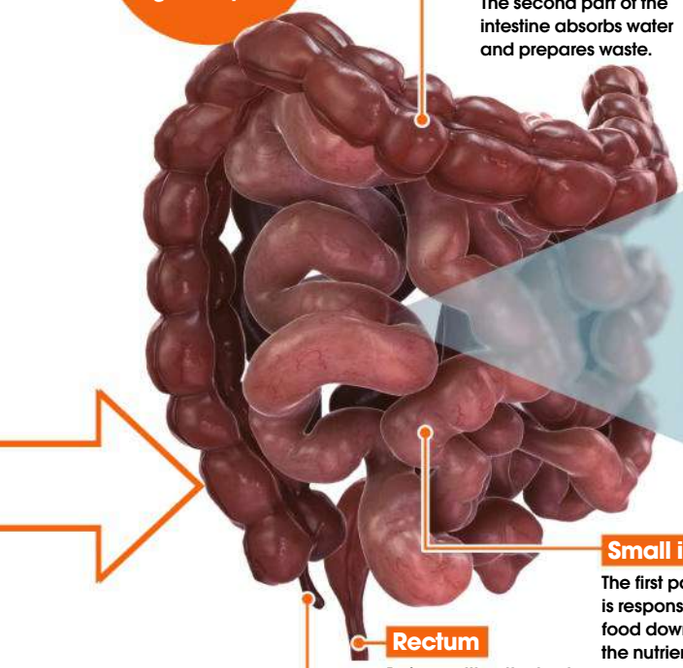
How the intestines work

The intestines are a crucial part of the digestive system that is heavily involved in breaking down and absorbing nutrients released from ingested food

4,500M²
The total absorptive surface area of the digestive system

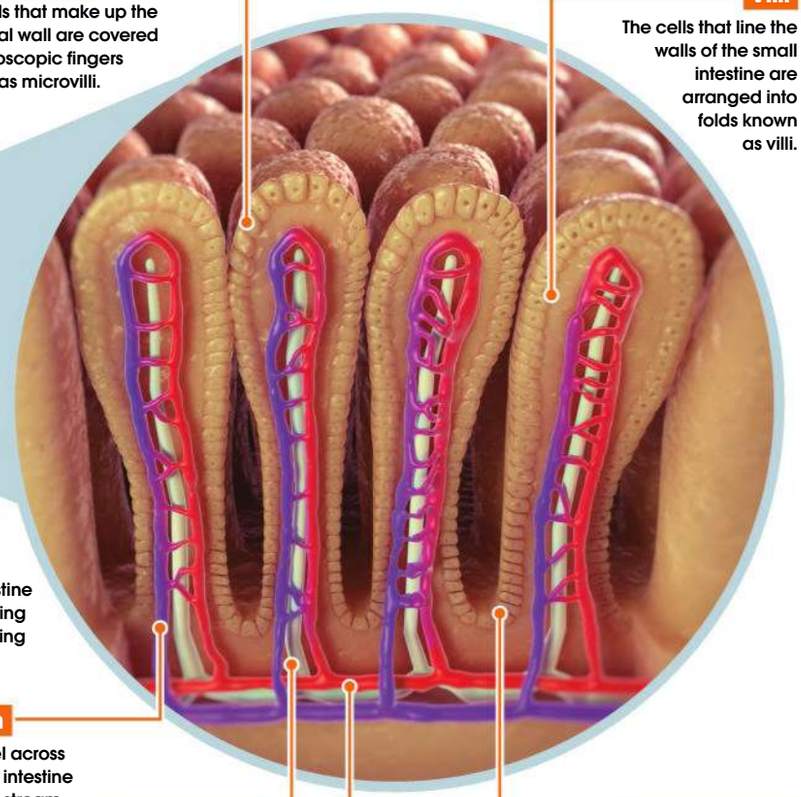


Large intestine
The second part of the intestine absorbs water and prepares waste.

Small intestine
The first part of the intestine is responsible for breaking food down and absorbing the nutrients.

Rectum
Before exiting the body, waste products are stored in a small pouch known as the rectum.

Appendix
Near the start of the large intestine is a blind-ending tube known as the appendix – its function is largely unknown.



Brush border
The cells that make up the intestinal wall are covered in microscopic fingers known as microvilli.

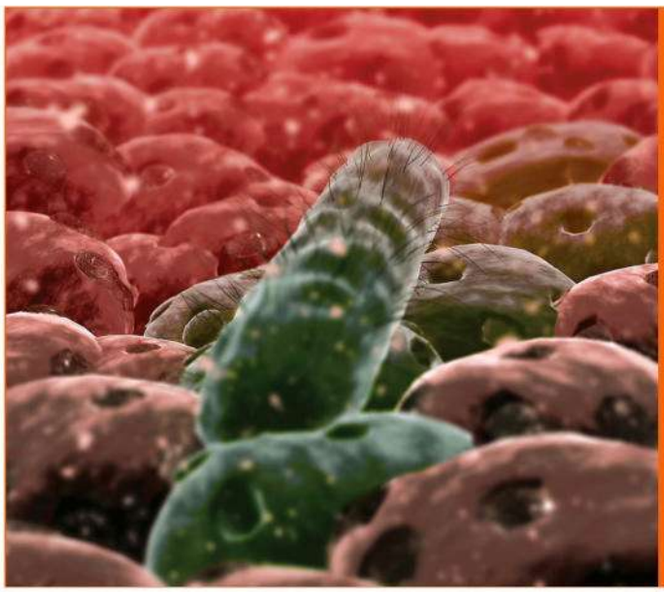
Villi
The cells that line the walls of the small intestine are arranged into folds known as villi.

Small vein
Nutrients travel across the wall of the intestine into the blood stream.

Lymph vessel
Fatty acids are transported away from the intestines via the lymphatic system.

Small artery
Each of the villi has a rich blood supply.

Intestinal crypt
Between the villi are crypts containing mucus-producing cells.



Living with bacteria

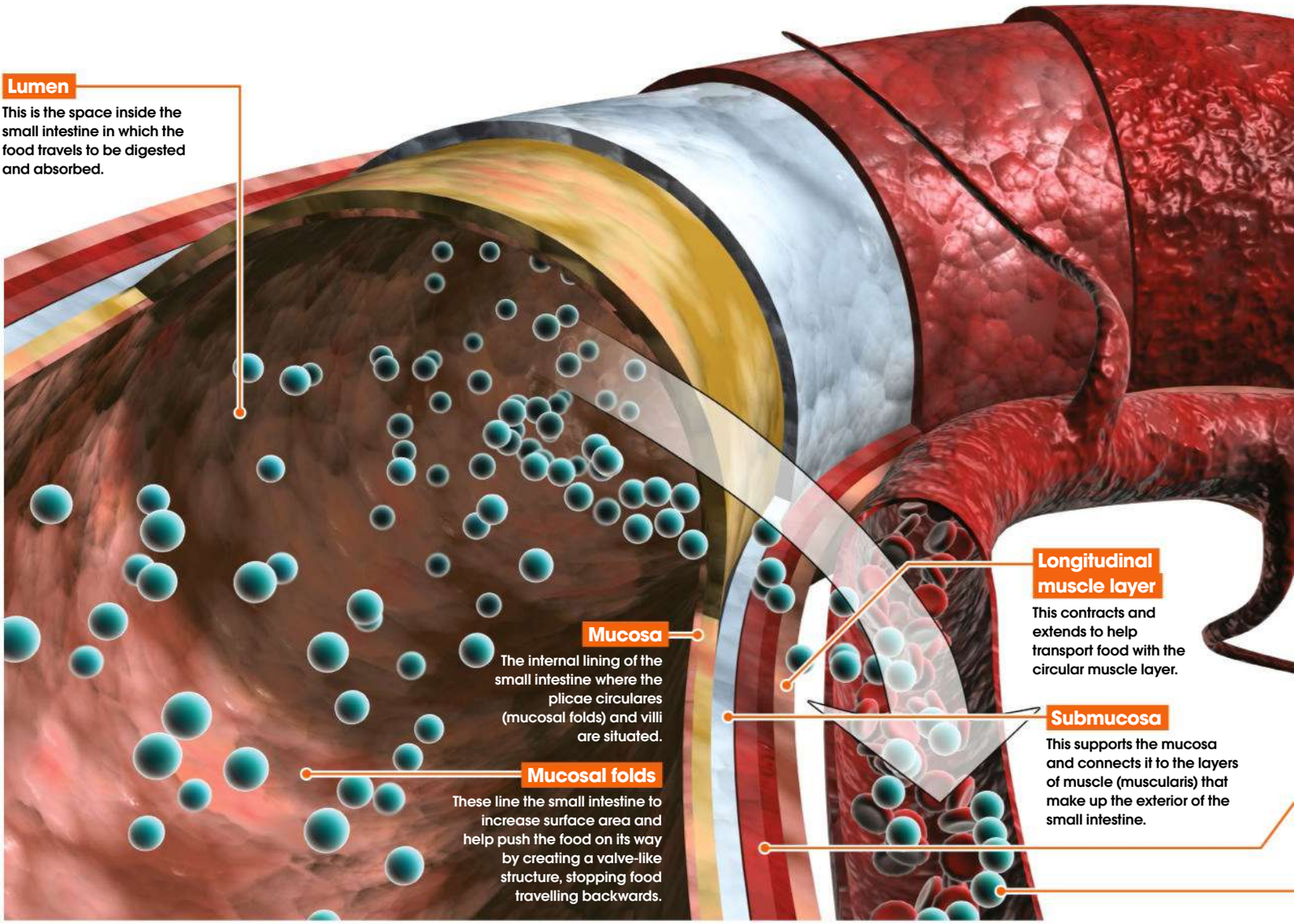
Bacteria are often portrayed as the 'bad guys' of the body, but the proportion that cause food poisoning is surprisingly small. In fact, bacteria start to move into your digestive system from the moment you are born, and a healthy adult has around 300 to 500 different resident species living in their large intestine at any one time.

The upper parts of the digestive system are hostile to microorganisms; the stomach is highly acidic and the small intestine is filled with digestive enzymes, but the large intestine provides the perfect environment for sustaining a microscopic world.

By the time food reaches this point, our digestive enzymes have done their work and most of the nutrients have been absorbed, but bacteria have a different set of enzymes. They are able to break indigestible material down even further, allowing us to absorb even more nutrients, mainly in the form of fatty acids.

The presence of these helpful bacteria also means there is little space or resources left for dangerous pathogens, helping to keep infections at bay.

The gut and its resident bacteria are in constant communication, picking up on chemical signals released into the environment. These signals can have far-reaching effects, and the types of bacteria present in your intestines have been shown to influence other organs, including the brain.



Exploring the small intestine

Crucial for getting the nutrients we need from the food we eat, how does this digestive organ work?

The small intestine is actually one of the most important elements of our digestive system, which enables us to process food and absorb nutrients. On average, it sits at a little over six metres, that is 19.7 feet, long with a diameter of 2.5-3 centimetres, 1-1.2 inches. The small intestine is made up of three different distinctive parts: the duodenum, jejunum and the ileum.

The duodenum actually connects the small intestine to the stomach and is the key place for further enzyme breakdown, following already passing through the stomach, turning food into an amino acid state. While the duodenum is very important in breaking food down, using bile and enzymes from the gallbladder, liver and pancreas, it is actually the shortest element of the small bowel, only averaging about 30 centimetres, which is just 11.8 inches.

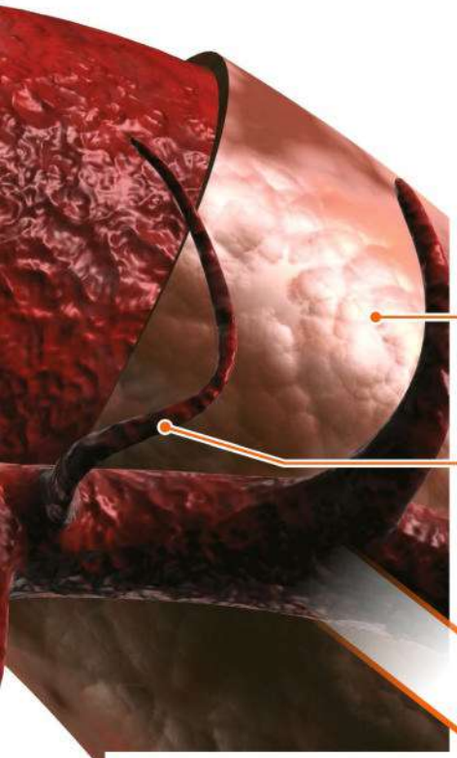
The jejunum follows the duodenum and its main function is to encourage absorption of carbohydrates and proteins by passing the broken-down food molecules through an area with a large surface area so they can enter the bloodstream. Villi – small finger-like structures – and mucosal folds line the passage and increase the surface area dramatically to aid this process.

The ileum is the final section of the small bowel and its main purpose is to catch nutrients that may have been missed, as well as absorbing vitamin B12 and bile salts.

Peristalsis is the movement used by the small intestine to push the food through to the large bowel, where waste matter is stored for a short period then disposed of via the colon. This process is generated by a series of muscles which make up the organ's outer wall.

Structure of the small intestine

Examine the anatomy of this vital organ in the human digestive tract

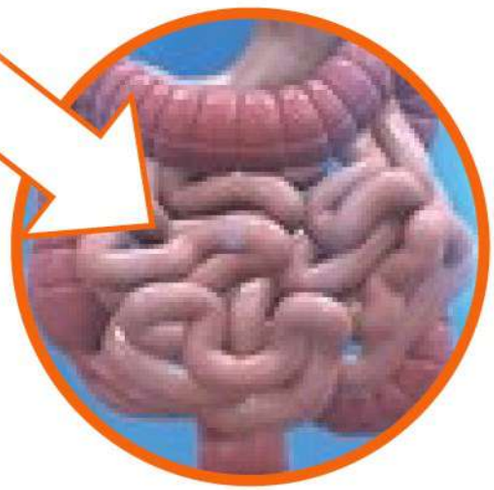


Serosa

This protective outer layer stops the small intestine from being damaged by other organs.

Blood vessels

These sit close to the small intestine to allow easy diffusion of nutrients into the bloodstream.



Circular muscle layer

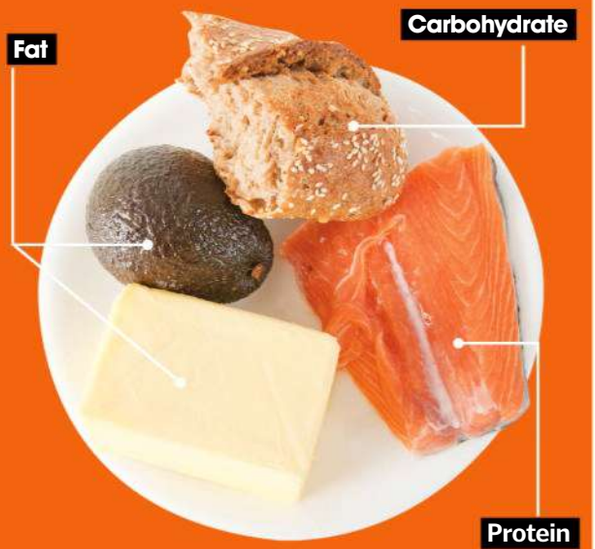
This works in partnership with the longitudinal muscle layer to push the food down via a process called peristalsis.

Nutrients

Nutrients move through the tube-like organ to be diffused into the body, mainly via the bloodstream.

What exactly are nutrients?

There are three main types of nutrient that we process in the body: lipids (fats), carbohydrates and proteins. These three groups of molecules are broken down into sugars, starches, fats and smaller, simpler molecule elements, which we can absorb through the small intestine walls and that then travel in the bloodstream to our muscles and other areas of the body that require energy or to be repaired. We also need to consume and absorb vitamins and minerals that we can't synthesise within the body, eg vitamin B12 (prevalent in meat and fish).



A closer look at villi

What role do these little finger-like protrusions play in the bowel?

Villi

Villi are tiny finger-like structures that sit all over the mucosa. They help increase the surface area massively, alongside the mucosal folds.

Epithelium (epithelial cells)

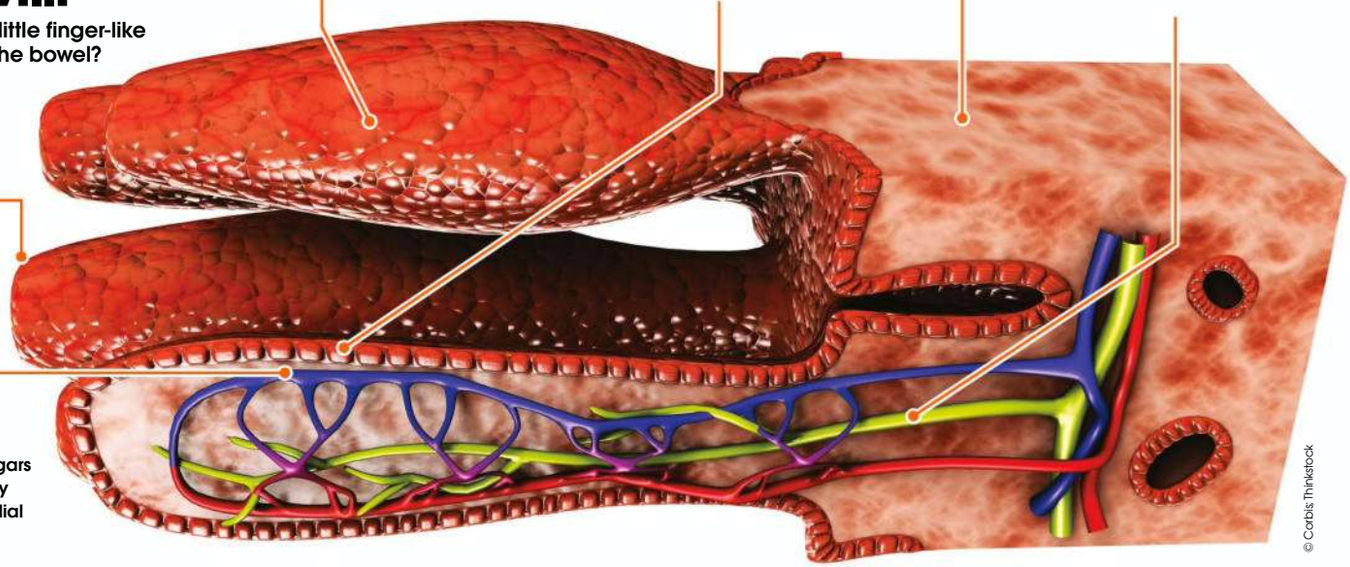
These individual cells that sit in the mucosa layer are where individual microvilli extend from.

Mucosa

The lining of the small intestine on which villi are located.

Lacteal

The lacteal is a lymphatic capillary that absorbs nutrients that can't pass directly into the bloodstream.



Microvilli

These are a mini version of villi and sit on villi's individual epithelial cells.

Capillary bed

These absorb simple sugars and amino acids as they pass through the epithelial tissue of the villi.

© Corbis Thinkstock

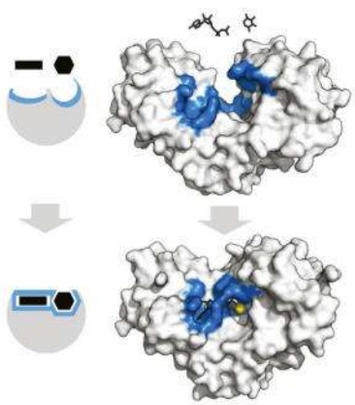
Enzymes

Get to know how these useful 'catalysts' help digestion

Enzymes are often called 'biological catalysts', and their job is to speed up chemical reactions. You are full of dissolved chemicals with the potential to come together or break apart to form the biological building blocks that you need to stay alive, but the reactions happen too slowly on their own.

Enzymes are molecules with 'active sites' that lock on to other molecules, bringing them close together so that they can react, or bending their structures so that they can combine or break apart more easily. The enzymes themselves do not actually get involved in the reactions; they just help them to happen faster.

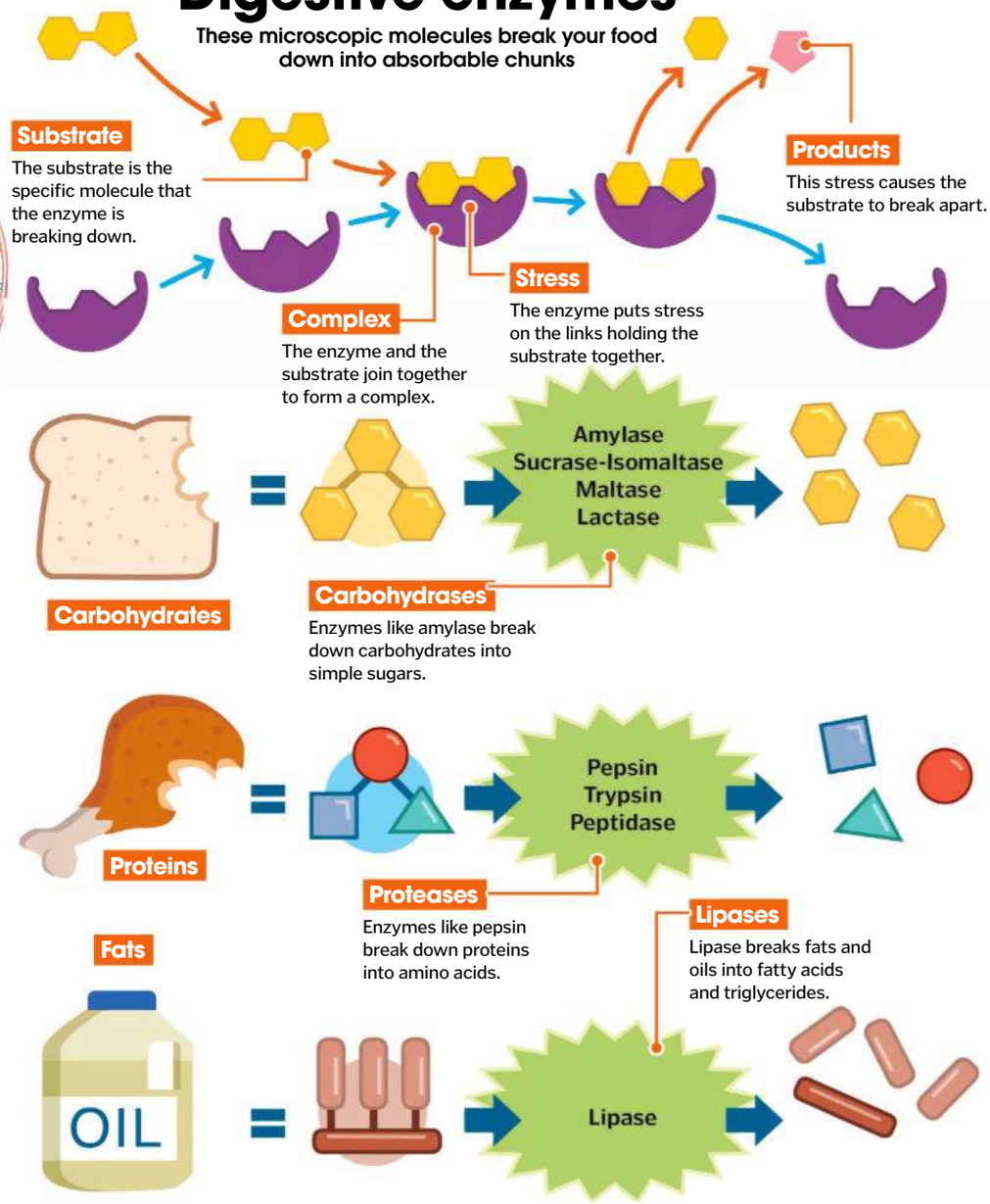
Some of the most well-known enzymes are those in your digestive system. These are important for breaking down the molecules in your food. However, these aren't the only enzymes in your body. There are others that help building molecules, snipping molecules, tidying up when molecules are no longer needed, and even destroying pathogens.



This enzyme brings two molecules close together so that they can react

Digestive enzymes

These microscopic molecules break your food down into absorbable chunks



Hunger is one of the body's most basic and fundamental sensations, and it originates in the stomach. When the stomach is empty, it begins to produce a hormone known as ghrelin. This then travels to a region of the brain known as the hypothalamus.

The hypothalamus is responsible for maintaining a constant, optimum state; keeping the body at a set temperature, regulating hormones and monitoring hydration. The arrival of ghrelin is a signal that energy levels might be about to dip, so it triggers the production of a second hormone, neuropeptide Y. This hormone promotes eating.

The cue to stop eating is much more subtle. The stomach has stretch receptors, and will signal to the brain that it is full. But what happens if the stomach is empty, but there is already enough energy stored in the system? Fat stores produce a hormone known as leptin, which tells the brain exactly how much energy the body has in reserve.

When leptin levels are high, the hypothalamus makes hormones that suppress appetite. The trouble is that with high levels of fat, we can become resistant to the leptin message, similar to insulin resistance in type-II diabetes. If the brain does not know there is enough fat, we just keep eating.

Cravings are slightly different. These are generated not in the stomach, but in the brain. There are three main areas of the brain implicated in food cravings, the hippocampus, the insula and the caudate.

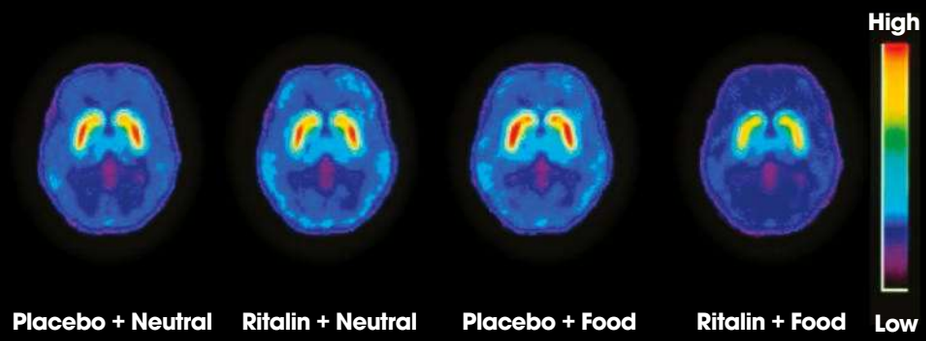
Humans have been programmed through evolution to enjoy fatty and sugary foods; eating them ensures we have enough energy to survive. The hippocampus is involved in gathering sensory information, and processing it for long-term memory storage, and with food cravings, these memories become associated with activation of the brain's reward circuitry. The more we enjoy eating a food, the more likely we are to crave it.

Mental images are thought to play an important role in food cravings and picturing food makes it much harder to resist. But thinking about other visual images can help to curb the cravings and distract your brain.

Digestion happens subconsciously, but it's worth noting that you do have a manual override in place, and what your brain thinks it wants isn't always what it needs.

Food addiction

Research into food addiction is relatively new and the results are hotly debated, but there is increasing evidence that food can elicit some of the same brain responses as addictive substances like cocaine. In overweight people, overeating can become a compulsion that is difficult to control, and has been shown to activate the same reward pathway that lights up when addictive drugs are ingested. In alcoholics, cocaine addicts and heroin addicts, the number of dopamine receptors in the reward pathway is lower than in the rest of the population and the same thing is found in obesity. It is thought that people with fewer dopamine receptors might need to over-stimulate their brains to experience the same rewards as normal people, and therefore turn to alcohol, drugs, or perhaps even food.



Food and the brain

Why do we crave these foods?

Comfort food

When we are feeling stressed or sad, many people turn to comfort foods such as mashed potatoes, beans on toast or macaroni cheese. Carbohydrates not only make us feel warm and full, they actually increase levels of serotonin, sometimes known as the happy hormone.

Sweets

Sugary foods are craved for many reasons, the simplest of which is that your body needs an energy boost. However, eating sugar is just a temporary fix, and as the sugar is rapidly cleared from the blood, the craving will quickly return.

Salty snacks

Animals have what is known as a 'salt appetite', similar to thirst, which drives them to seek out salt when they are running low. However, there is little evidence for an equivalent trait in humans. Men are more likely to crave salty foods than women, though.

The gut-brain axis

How does the bacteria in your gut act like a 'second brain'?

There is an increasing amount of evidence to suggest that the activity of bacteria in your gut can significantly affect your brain. This relationship is called the gut-brain axis, and while its exact mechanisms and significance haven't been deciphered, it's thought that the microbes in your digestive tract are responsible for complex interactions between your digestive system and nervous, endocrine and immune systems. Your intestines are filled with bacteria that help break down food, produce vital nutrients and defend us against harmful bacteria. Scientists speculate that gut microbes can send signals to the brain via three different methods.

The first involves bacteria releasing neurotransmitters (chemicals that help to transmit nerve impulses) to trigger the neurons in your digestive tract, which in turn send signals to your brain via the vagus nerve. Some studies have shown that certain species of gut bacteria can produce serotonin, an important neurotransmitter that plays a role in regulating your appetite and mood.

A second proposed method is that microbes in the gut produce molecules called metabolites when they break down our food. These can stimulate an increase in the production of neurotransmitters by cells that line the gut (epithelial cells), which activate the vagus nerve. A recent study found that some gut microbes can produce the fatty acids butyrate and tyramine, which promote the production of serotonin by certain cells.

The third hypothesis is that gut bacteria can influence the brain indirectly by triggering the immune system. Gut bacteria can stimulate immune cells to produce small proteins called cytokines, which travel through the bloodstream to the brain. It is thought that these proteins can influence the development and activity of microglia (the brain's immune cells), which are responsible for removing damaged cells at an injury site. Researchers believe microglia also play a role in metabolism.

Although there are few human studies at the moment, animal studies have linked the activity of gut bacteria to a variety of conditions, including Parkinson's disease, obesity, depression, anxiety, schizophrenia, cardiovascular disease, and even strokes.

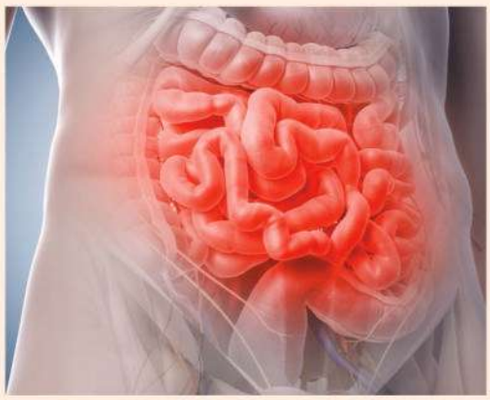
While more research is needed, if links are proven it could revolutionise how we treat neurological disorders, such as probiotic diets to supplement treatments.

Bacterial boost

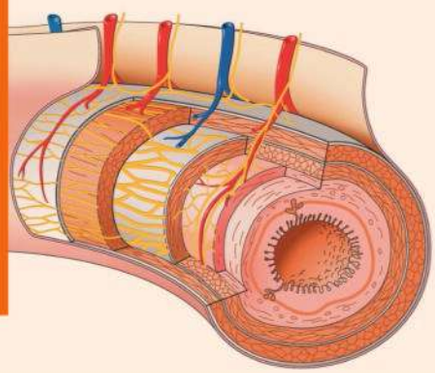
Two recent studies, one French and one American, have shown that gut bacteria can influence response to cancer treatments. Both studies involved patients undergoing immunotherapy, which encourages immune cells to recognise and attack tumours.

The French study involved 249 patients with kidney, bladder or lung cancers, 69 of whom had taken antibiotics for routine infections. Antibiotics disrupt the microbiome, affecting both 'good' and 'bad' bacteria. On average, patients who took antibiotics during treatment were more likely to have relapses and did not survive as long as those who didn't. The authors then compared the differences in the patients' microbiomes and found that the presence a species called Akkermansia muciniphila was linked to the improved immunotherapy results.

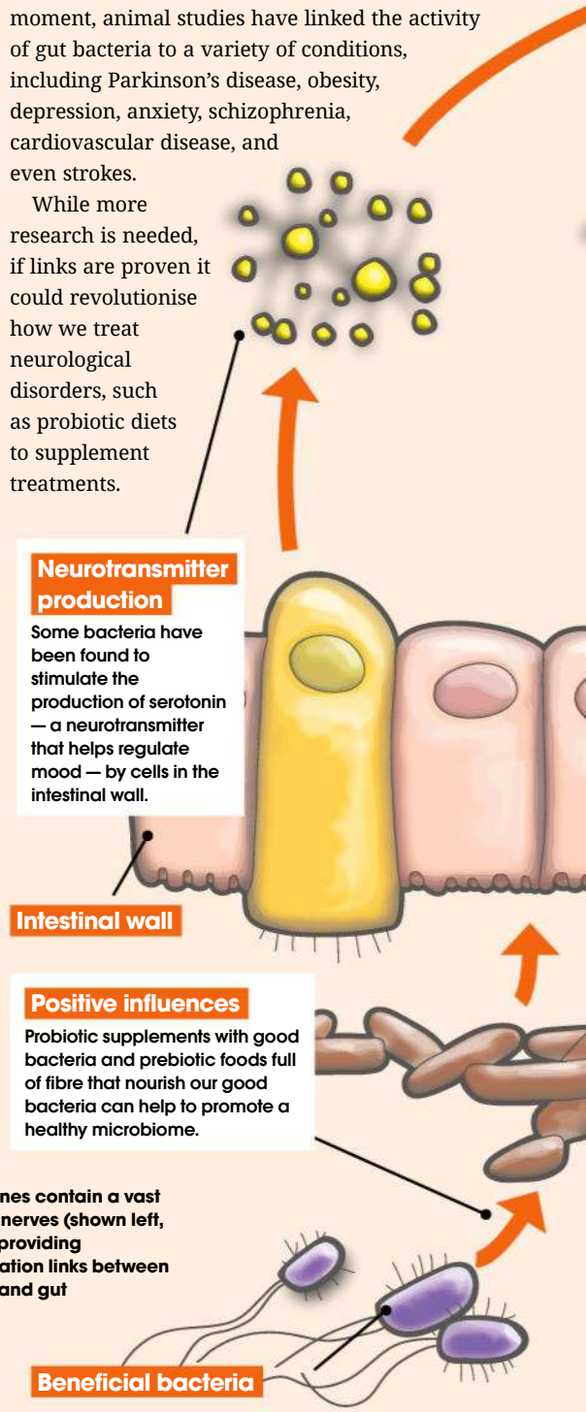
The US study also compared the different gut bacteria present in 112 melanoma patients. Patients who responded well to treatment were more likely to have more diverse microbiomes and higher numbers of certain beneficial species including Clostridiales and Faecalibacterium. Patients with more of these 'good' bacteria were found to have more cancer-killing immune cells in their tumours.



Scientists are only just beginning to understand the impact your microbiome can have on your brain

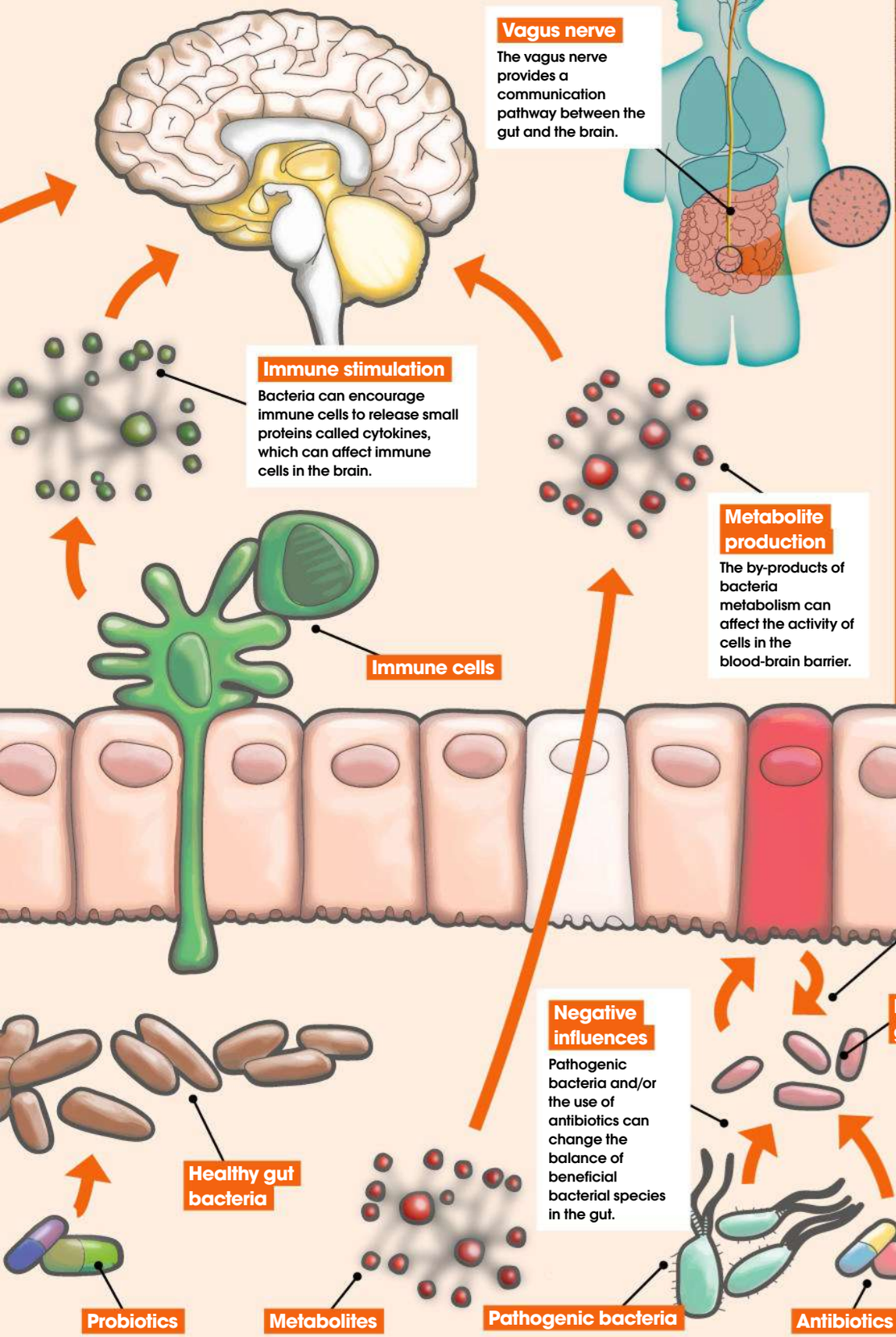


Your intestines contain a vast network of nerves (shown left, in yellow), providing communication links between your brain and gut



Gut feeling

How can your microbiome influence your brain?



Fermented foods, such as sauerkraut and kimchi, contain probiotics

Probiotics & prebiotics

Given the potential impact gut bacteria can have on overall health, the old phrase 'you are what you eat' appears to ring true.

We can promote the growth of good bacteria through our diets by incorporating probiotics (foods containing live good bacteria) and prebiotics (foods containing beneficial plant fibres). Probiotics can be found in certain yoghurts, cheeses and fermented foods. Prebiotics, on the other hand, are used as a food source for beneficial bacteria to grow and survive in the gut. When they digest the fibre we eat from vegetables, nuts and fruits they excrete short-chain fatty acids as waste products, which are great for nourishing our intestines and reducing inflammation.

Research suggests we need a diverse range of bacteria to have a really healthy gut, but modern high-fat and high-sugar diets have been found to decrease the number of different species living in our intestines.

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A study involving gut microbe transplants between mice found that certain behavioural traits were also transferred, ie a previously shy mouse would explore more after receiving transplants of bacteria from a more adventurous mouse

The urinary system explained

How do we get rid of the waste products that enter the bloodstream every day?

The human urinary system's primary function is to remove by-products which remain in the blood after the body has metabolised food. The process is made up of several different key features. Generally, this system consists of two kidneys, two ureters, the bladder, two sphincter muscles (one internal, one external) and a urethra and these work alongside the intestines, lungs and skin, all of which excrete waste products from the body.

The abdominal aorta is an important artery to the system as this feeds the renal artery and vein, which supply the kidneys with blood. This blood is filtered by the kidneys to remove waste products, such as urea which is formed through amino acid metabolism. Through communication with other areas of the body, such as the hypothalamus, the kidneys also control water levels in the body, sodium and potassium levels among other electrolytes, blood pressure, pH of the blood and are also involved in red blood cell production through the creation and release of the hormone erythropoietin. Consequently, they are absolutely crucial to optimum body operation.

After blood has been filtered by the kidneys, the waste products then travel down the ureters to the bladder. The bladder's walls expand out to hold the urine until the body can excrete the waste out through the urethra. The internal and external sphincters then control the release of urine.

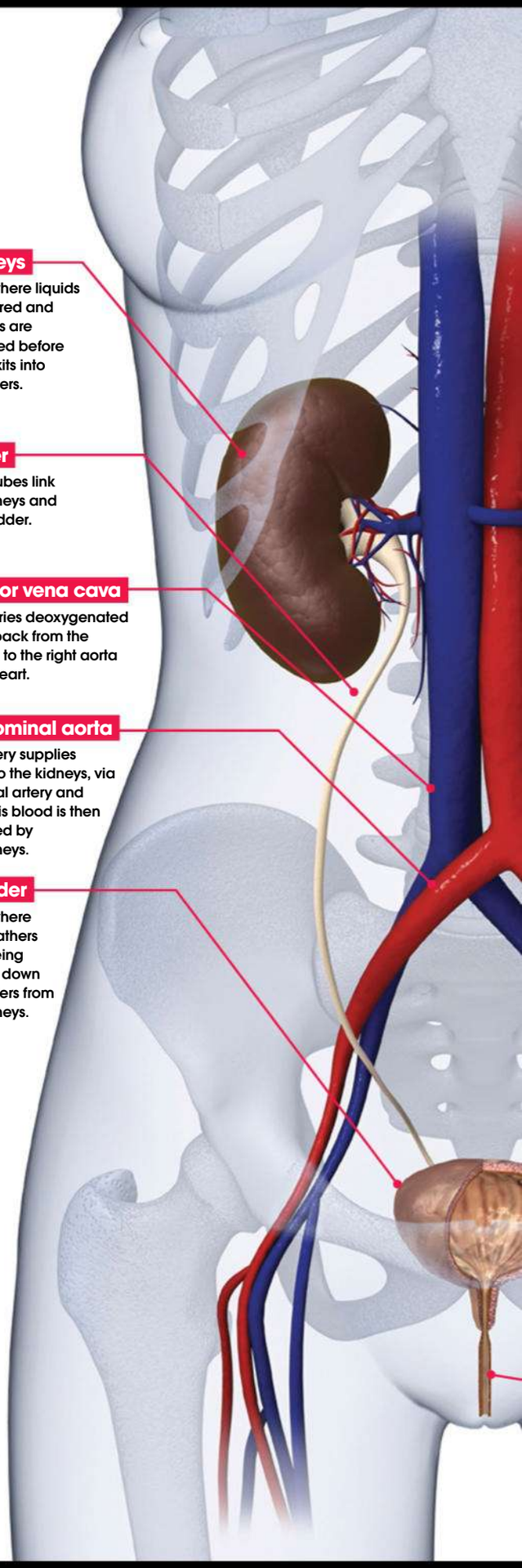
On average, a typical human will produce approximately 2.5-3 litres (4.4-5.3 pints) of urine in just one day, although this can vary dramatically dependant on external factors such as how much water is consumed.

"Generally, a human will produce 2.5-3 litres of urine a day"

How do the kidneys work?

The kidneys will have around 150-180 litres (264-317 pints) of blood to filter per day, but only pass around two litres (3.5 pints) of waste down the ureters to the bladder for excretion, therefore the kidneys return much of this blood, minus most of the waste products, to the heart for re-oxygenation and recirculation around the body.

The way the kidneys do this is to pass the blood through a small filtering unit called a nephron. Each kidney has around a million of these, which are made up of a number of small blood capillaries and a tube called the renal tubule. The blood capillaries sift the normal cells and proteins from the blood for recirculation and then direct the waste products into the renal tubule. This waste, which will primarily consist of urea, mixes with water and forms urine as it passes through the renal tubule and then into the ureter on its way to the bladder.



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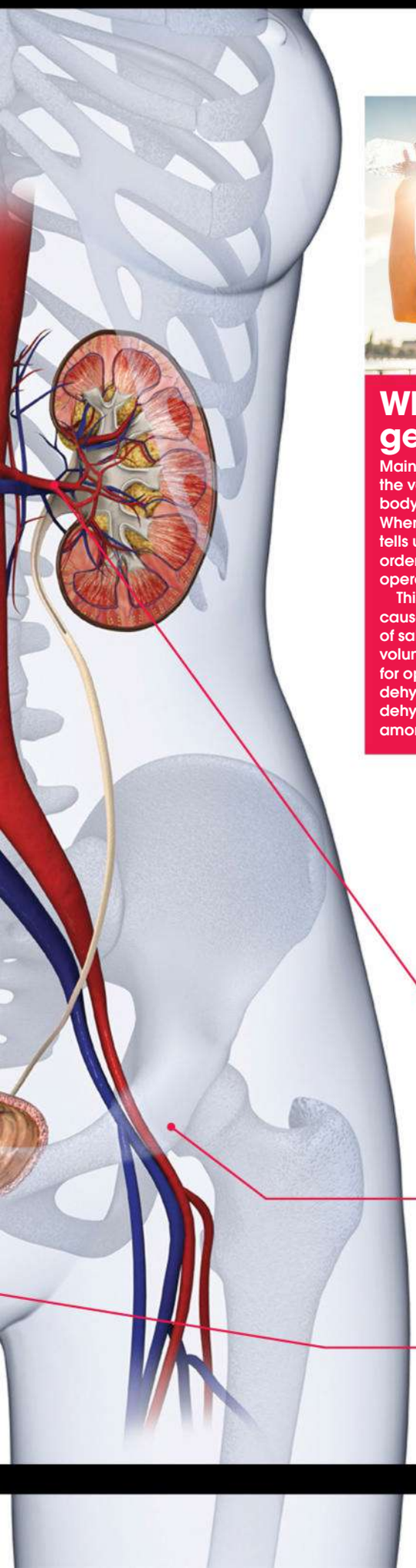


Why do we get thirsty?

Maintaining the balance between the various minerals and salts in our body and water is very important. When this is out of harmony, the body tells us to consume more liquids in order for the body to continue operating effectively.

This craving, or thirst, can be caused by too high a concentration of salts in the body, or by the water volume in the body dropping too low for optimal operation. Avoiding dehydration is important as long-term dehydration can cause renal failure, among other conditions.

Human urinary system

Renal artery and vein
This supplies blood to the kidneys in order for them to operate, and then removes deoxygenated blood after use by the kidneys.

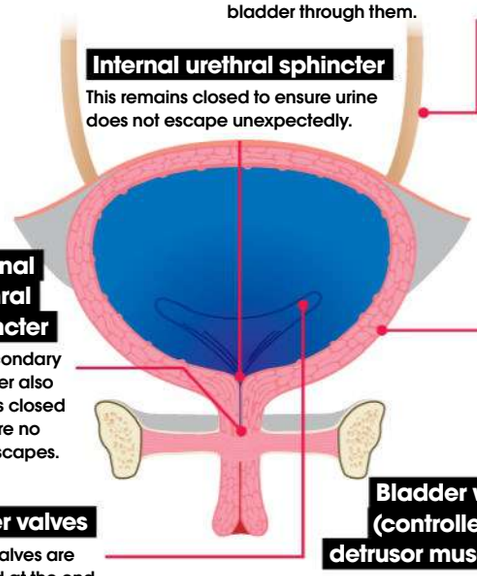
Pelvis
The bladder sits in the pelvis, and the urethra passes through it for urine to exit the body.

Urethra
The urethra is the tube that urine travels through to exit the body.

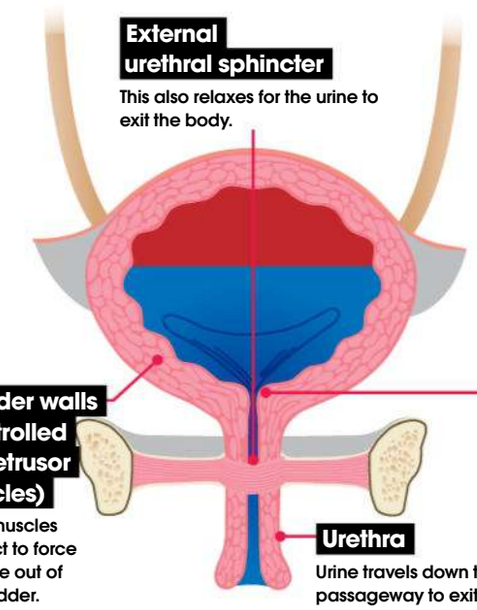
How do we store waste until we're ready to expel it?

Urine enters the bladder through the ureter valves, which attach the ureter to the bladder. The walls relax as urine enters, allowing the bladder to stretch. When the bladder is full, the nerves in the bladder communicate with the brain and trigger the urge to urinate. The internal and external sphincters will then relax, allowing urine to pass down the urethra.

Bladder fills



Bladder empties



Kidney function

How do your kidneys filter waste from the blood to keep you alive?

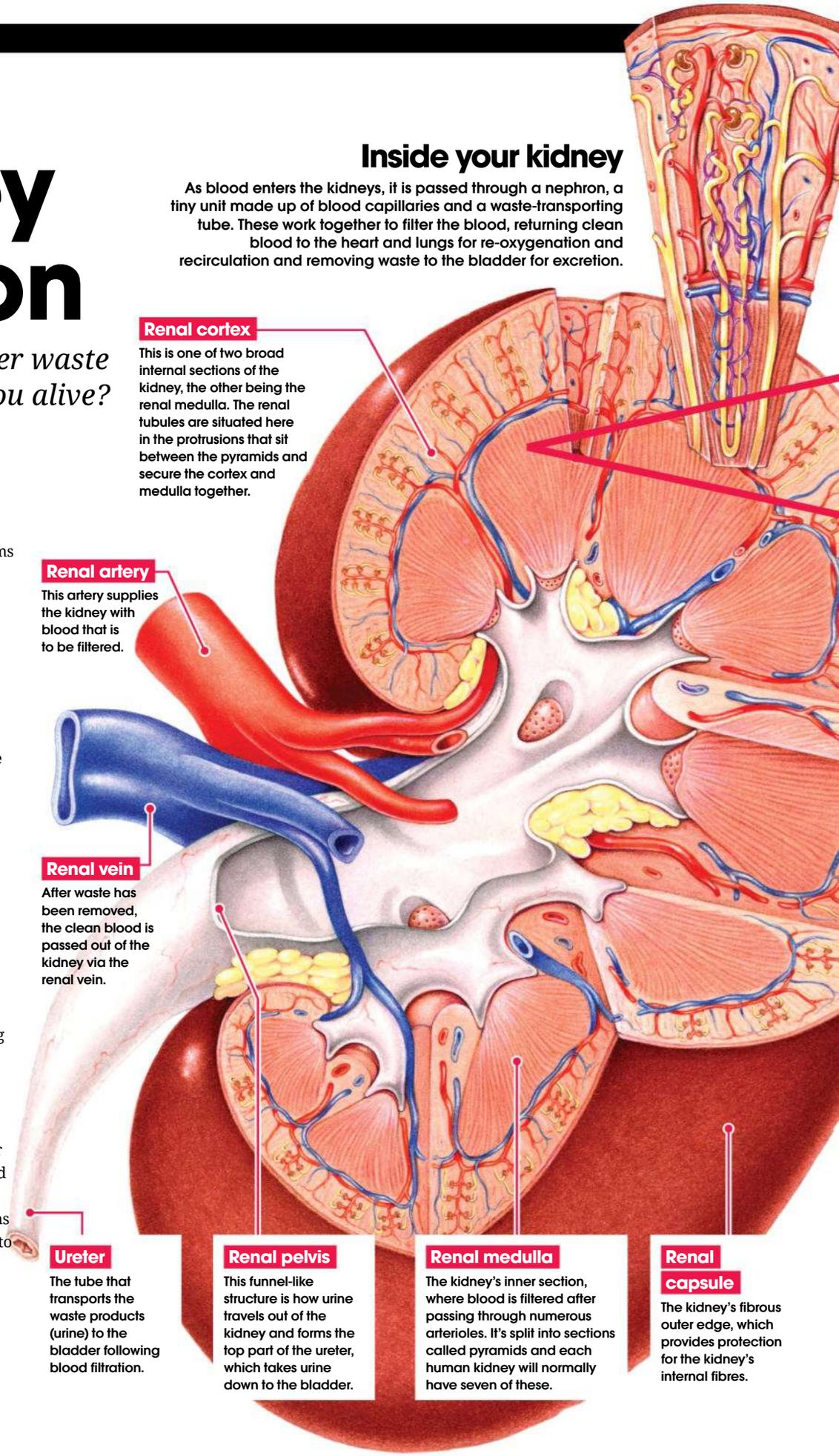
Kidneys are two bean-shaped organs situated halfway down the back just under the ribcage, on each side of the body, and weigh 115-170 grams (4-6 ounces) each, dependent on the individual's sex and size. The left kidney is often a little larger than the right and due to the effectiveness of these organs, individuals born with one kidney can survive with little or no health problems. Indeed, the body can operate normally with a 30-40 percent decline in kidney function. This decline would rarely even be noticeable and shows just how effective the kidneys are at filtering out waste products as well as maintaining mineral levels and blood pressure throughout the body. The kidneys manage to control all of this by working with other organs and glands across the body such as the hypothalamus, which helps the kidneys determine and control water levels in the body.

Each day the kidneys will filter 150-180 litres (263-317 pints) of blood, but only pass around two litres (3.5 pints) of waste down the ureters to the bladder for excretion. This waste product is primarily urea – a by-product of protein being broken down for energy – and water, and it's more commonly known as 'urine'. The kidneys filter the blood by passing it through a small filtering unit called a nephron. Each kidney has around a million of these, made up of a number of small blood capillaries, called glomerulus, and a urine-collecting tube called the renal tubule. The glomerulus sift the normal cells and proteins from the blood and move the waste products into the renal tubule, which transports urine down into the bladder through the ureters.

The kidneys also release three hormones (erythropoietin, renin and calcitriol) which encourage red blood cell production, regulate blood pressure and aid bone development and mineral balance respectively.

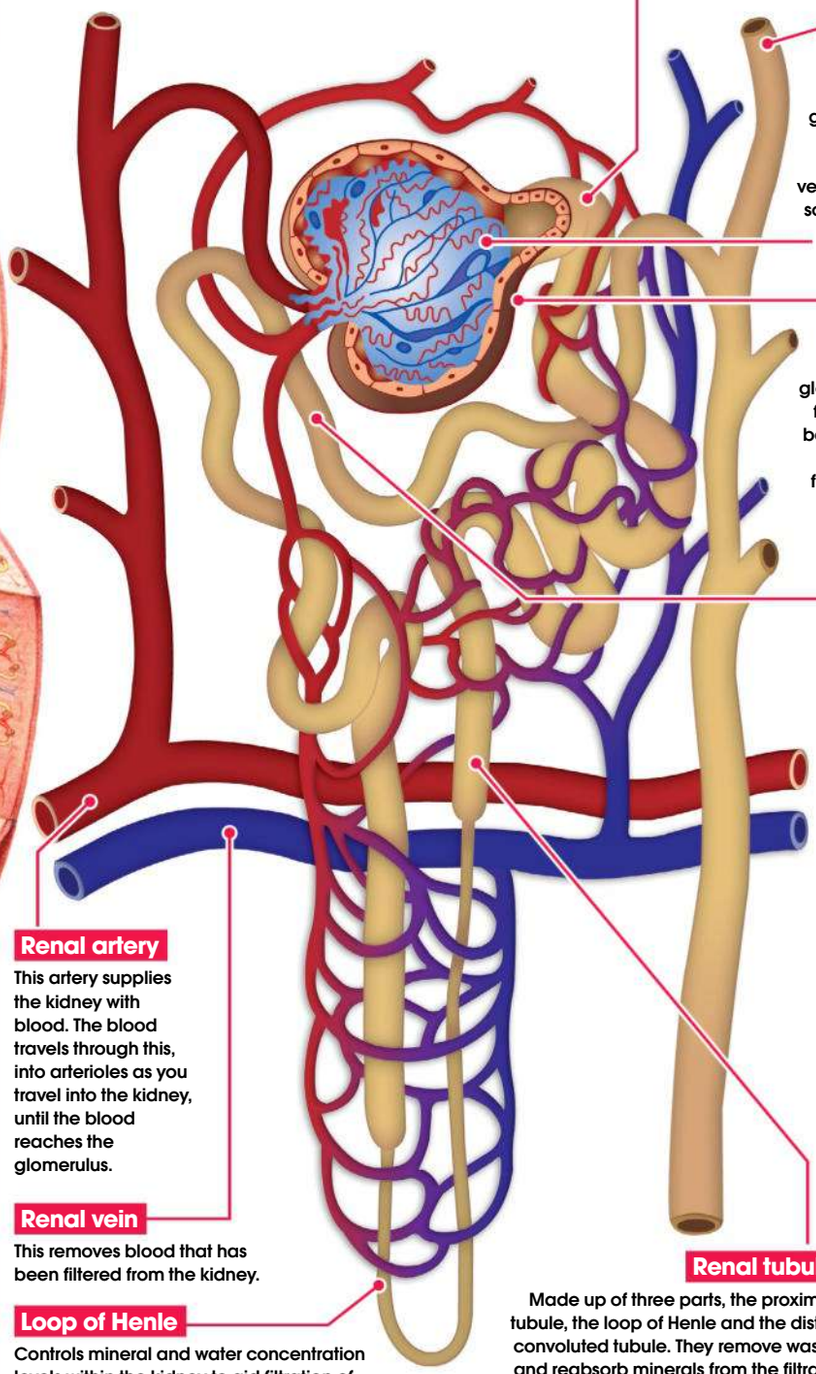
Inside your kidney

As blood enters the kidneys, it is passed through a nephron, a tiny unit made up of blood capillaries and a waste-transporting tube. These work together to filter the blood, returning clean blood to the heart and lungs for re-oxygenation and recirculation and removing waste to the bladder for excretion.



Nephrons – the filtration units of the kidney

Nephrons are the units which filter all blood that passes through the kidneys. There are around a million in each kidney, situated in the renal medulla's pyramid structures. As well as filtering waste, nephrons regulate water and mineral salt by recirculating what is needed and excreting the rest.



Proximal tubule
Links Bowman's capsule and the loop of Henle, and will selectively reabsorb minerals from the filtrate produced by Bowman's capsule.

Collecting duct system
Although not technically part of the nephron, this collects all waste product filtered by the nephrons and facilitates its removal from the kidneys.

Glomerulus
High pressure in the glomerulus, caused by it draining into an arteriole instead of a venule, forces fluids and soluble materials out of the capillary and into Bowman's capsule.

Bowman's capsule
Also known as the glomerular capsule, this filters the fluid that has been expelled from the glomerulus. Resulting filtrate is passed along the nephron and will eventually make up urine.

Distal convoluted tubule
Partly responsible for the regulation of minerals in the blood, linking to the collecting duct system. Unwanted minerals are excreted from the nephron.

Renal artery
This artery supplies the kidney with blood. The blood travels through this, into arterioles as you travel into the kidney, until the blood reaches the glomerulus.

Renal vein
This removes blood that has been filtered from the kidney.

Loop of Henle
Controls mineral and water concentration levels within the kidney to aid filtration of fluids. It also controls urine concentration.

Renal tubule
Made up of three parts, the proximal tubule, the loop of Henle and the distal convoluted tubule. They remove waste and reabsorb minerals from the filtrate passed on from Bowman's capsule.

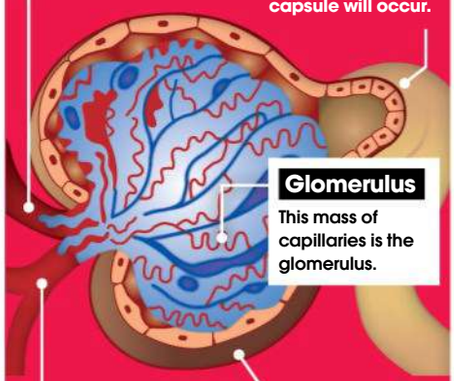
© DK Images

The glomerulus

This group of capillaries is the first step of filtration and a crucial aspect of a nephron. As blood enters the kidneys via the renal artery, it is passed down through a series of arterioles which eventually lead to the glomerulus. This is unusual, as instead of draining into a venule (which would lead back to a vein) it drains back into an arteriole, which creates much higher pressure than normally seen in capillaries, which in turn forces soluble materials and fluids out of the capillaries. This process is known as ultrafiltration and is the first step in filtration of the blood. These then pass through the Bowman's capsule (also know as the glomerular capsule) for further filtration.

Afferent arteriole
This arteriole supplies the blood to the glomerulus for filtration.

Proximal tubule
Where reabsorption of minerals from the filtrate from Bowman's capsule will occur.



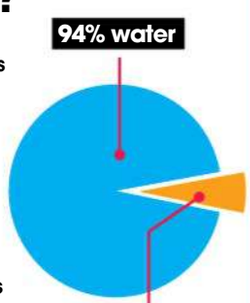
Glomerulus
This mass of capillaries is the glomerulus.

Efferent arteriole
This arteriole is how blood leaves the glomerulus following ultrafiltration.

Bowman's capsule
This is the surrounding capsule that will filter the filtrate produced by the glomerulus.

What is urine and what is it made of?

Urine is made up of a range of organic compounds, such as various proteins and hormones, inorganic salts and numerous metabolites. These are often rich in nitrogen and need to be removed from the blood stream through urination. The pH-level of urine is typically around neutral (pH7) but varies depending on diet, hydration levels and physical fitness. The colour of urine is also determined by all of these different factors, with dark-yellow urine indicating dehydration and greenish urine being indicative of excessive asparagus consumption.



Inside the liver

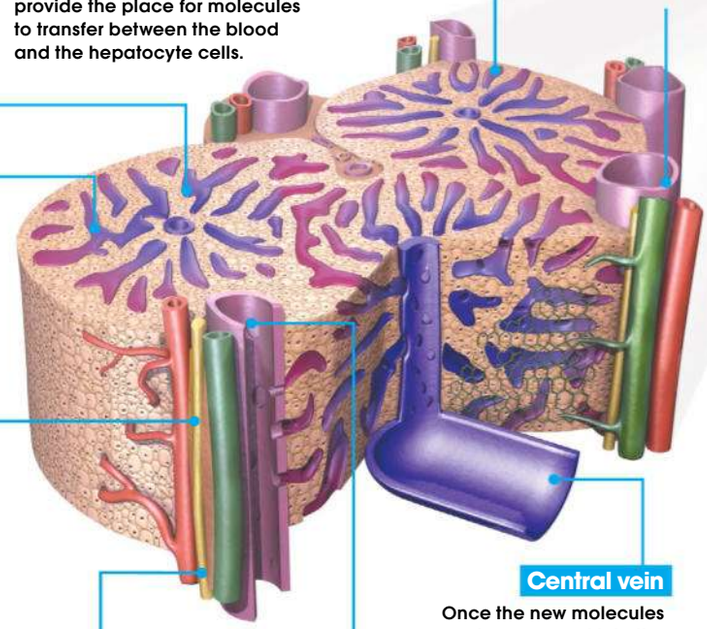
The human liver is the ultimate multitasker – it performs many different functions all at the same time without you even asking

Weighing more than a bag of sugar, the liver is the largest of all the internal organs. It's located mostly in the right side of your abdominal cavity and is capable of holding roughly ten percent of your body's total blood volume, with around a quarter of your blood supply passing through it every minute. The liver has over 500 different functions. In fact, it is actually the second most complex organ after the brain and is intrinsically involved in almost every aspect of the body's metabolic processes.

The liver's main functions are energy production, removal of harmful substances and the production of crucial proteins. These tasks are carried out within liver cells, called hepatocytes, which sit in complex arrangements to maximise their overall efficiency.

The liver is the body's main powerhouse, producing and storing glucose as a key energy source. It is also responsible for breaking down complex fat molecules and building them up into cholesterol and triglycerides. The body needs both of these, but they become a problem when an excess build up. The liver also makes many complex proteins, including clotting factors which are vital in arresting bleeding. The liver also plays a key role in detoxifying the blood.

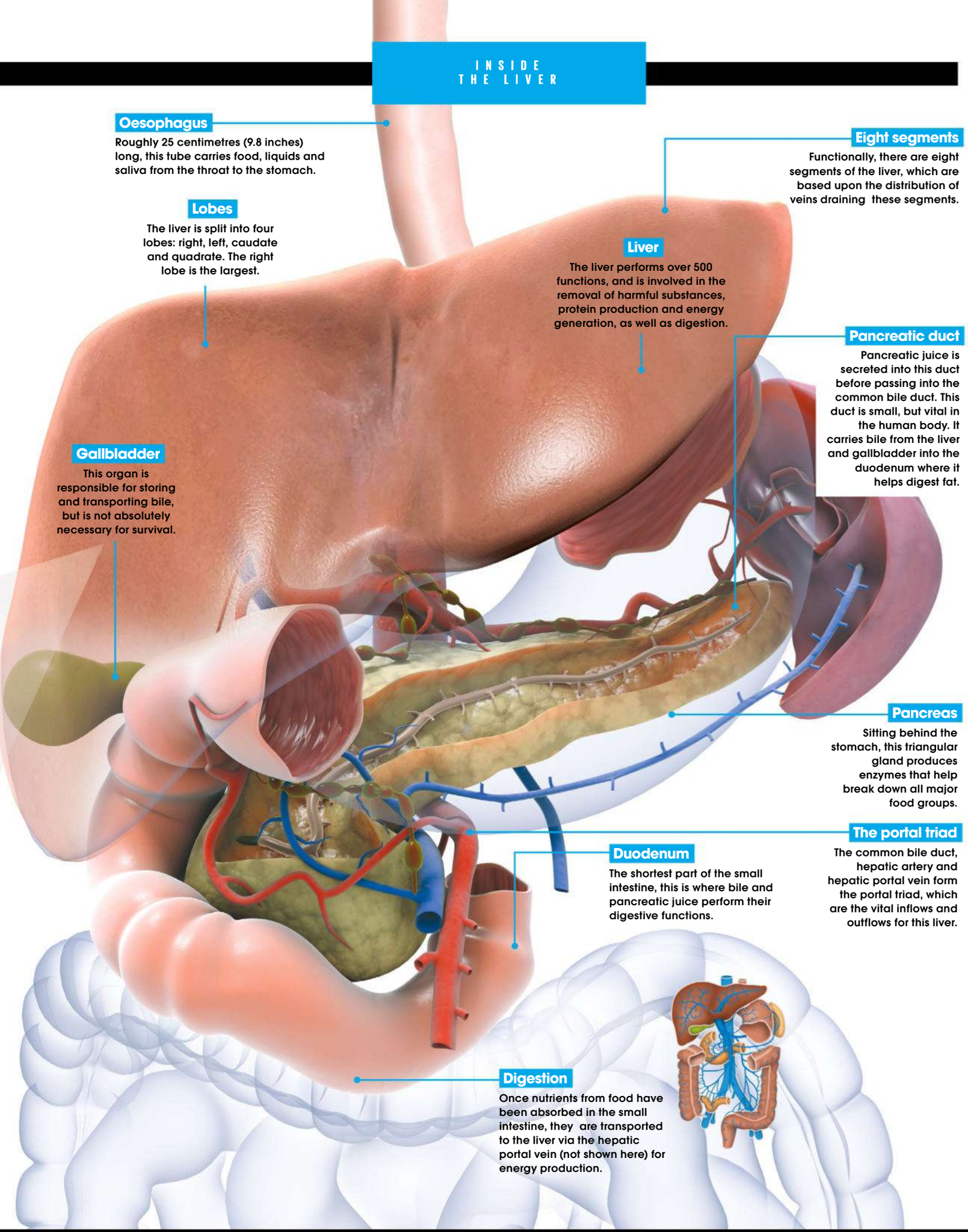
Waste products, toxins and drugs are processed here into forms that are easier for the rest of the body to use or excrete. The liver also breaks down old blood cells, produces antibodies to fight infection and recycles hormones such as adrenaline. Numerous essential vitamins and minerals are stored in the liver: vitamins A, D, E and K, iron and copper. Such a complex organ is also unfortunately prone to diseases. Cancers, infections (hepatitis) and cirrhosis (a form of fibrosis which is often caused by excess alcohol consumption) are just some of those which can affect the liver.



Liver lobules

The lobules consist of rows of hepatocytes (liver cells), bile ducts and blood vessels. Roughly 100,000 of these hexagonal-shaped structures sit within the organ, each consisting of a central vein surrounded by six hepatic portal veins and six hepatic arteries. These blood vessels are connected by sinusoids, which are small tubes joining the central vein to the surrounding veins and arteries. The products from digestion are transported in the blood to the sinusoids, where they can be absorbed into the hepatocytes.

INSIDE THE LIVER

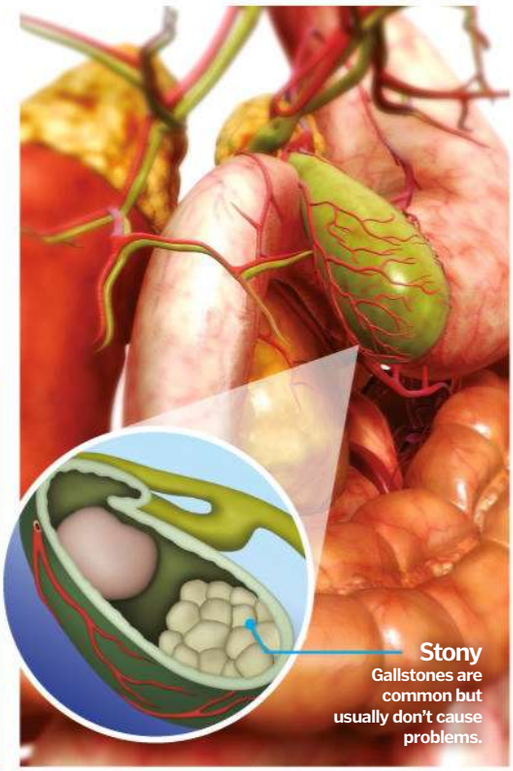


How do these vital organs work together to digest food?

Bile, which breaks up fat molecules to aid digestion in the intestines, is produced in the liver and stored in the adjacent gallbladder. Up to one litre of this greenish-yellow liquid is produced and released every day, containing a combination of salts, water, cholesterol and a pigment called bilirubin. Bile travels from the liver to the gallbladder, where it is stored. When a fat-containing food reaches the duodenum (part of the small intestine), the gallbladder is stimulated to secrete this bile, which travels through the bile duct and reaches the duodenum. Here it breaks down complex fat molecules into smaller, circular globules – a process called emulsification. These globules are smaller and have a larger total surface area, making them easier to digest. The pancreas also plays a role in digestion, as it produces substances that help to break down food. When the stomach and duodenum are stretched by the presence of a meal, the pancreas is triggered to deliver an assortment of enzymes in a cocktail known as pancreatic juice. An enzyme called amylase breaks down starches, while trypsin digests proteins and lipase works on fatty acids.

The gallbladder

Bile, a dark green slimy liquid, is produced in the hepatocytes and helps to digest fat. It is stored in a reservoir which sits on the under-surface of the liver, to be used when needed. This reservoir is called the gallbladder. Stones can form in the gallbladder (gallstones) and are very common, although most don't cause problems. In 2009, just under 60,000 gallbladders were removed from patients within the NHS making it one of the most common operations performed; over 90 percent of these are removed via keyhole surgery. Most patients do very well without their gallbladder and don't notice any changes at all.



Stony
Gallstones are common but usually don't cause problems.

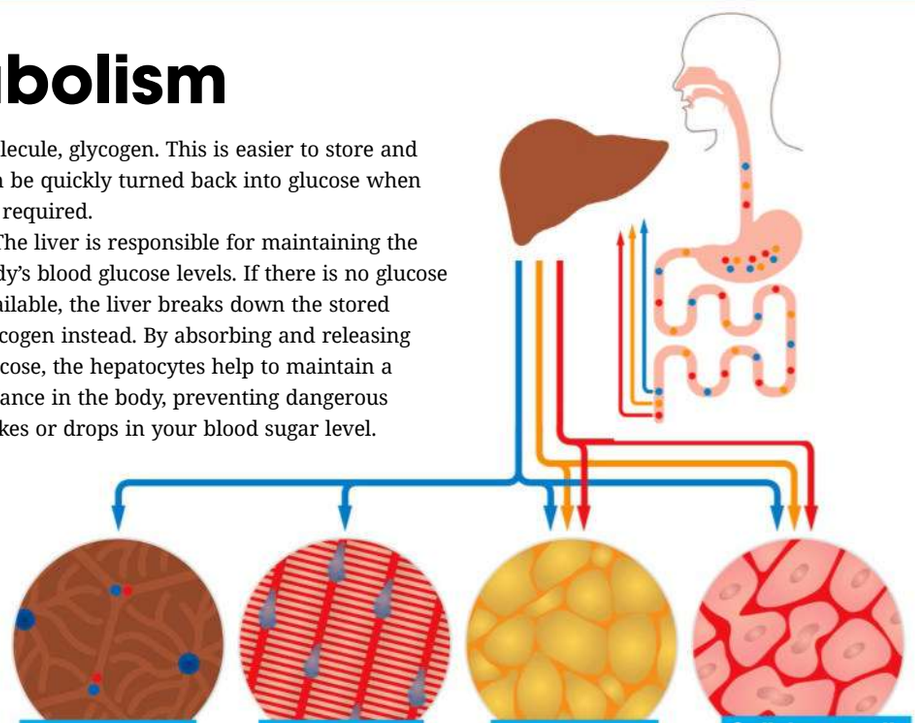
Liver metabolism

Metabolism is more than just the body's way of breaking down food into the energy we need to survive – it's the conversion of one chemical compound into another. In the liver, cells called hepatocytes perform many key metabolic tasks. These cells work to convert proteins, fats and carbohydrates into molecules that the body can use or store. For example, much of the glucose that passes through the liver is absorbed by the hepatocytes, which stockpile it as a larger molecule, glycogen. This is easier to store and can be quickly turned back into glucose when it's required.

The liver is responsible for maintaining the body's blood glucose levels. If there is no glucose available, the liver breaks down the stored glycogen instead. By absorbing and releasing glucose, the hepatocytes help to maintain a balance in the body, preventing dangerous spikes or drops in your blood sugar level.

A high demand organ

The liver deals with a massive amount of blood. It is unique because it has two blood supplies – 75 percent of this comes directly from the intestines (via the hepatic portal vein) which carries nutrients from digestion, which the liver processes and turns into energy. The rest comes from the heart, via the hepatic artery (which branches from the aorta), carrying oxygen which the liver needs to produce this energy. The blood flows in tiny passages in between the liver cells where the many metabolic functions occur. The blood then leaves the liver via the hepatic veins to flow into the biggest vein in the body – the inferior vena cava.



Hepatic tissue
If there is excess glucose in the body, the hormone insulin triggers the liver's hepatocyte cells to convert glucose into glycogen.

Muscle fibres
Both the liver's muscle cells and hepatic cells are able to store glycogen within them.

Adipose cells
These cells store excess fatty acids in the form of long-chain fat molecules.

Cellular growth and repair
A process called anabolism builds amino acids into proteins, which can then be used to construct cells and produce enzymes.

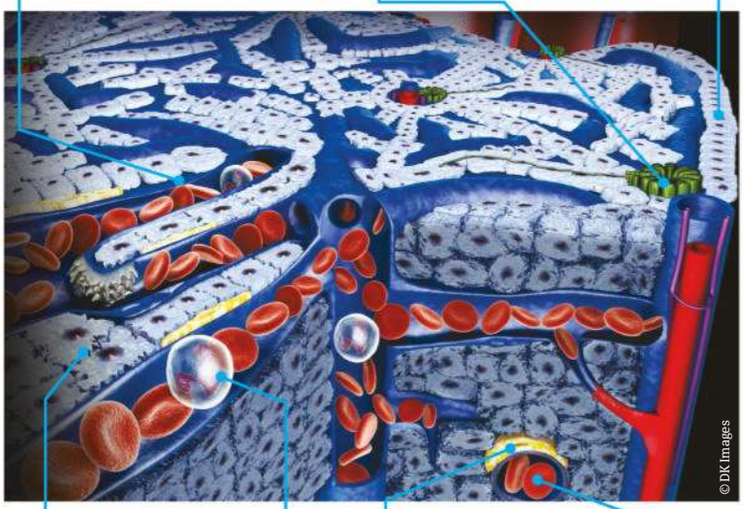
How does the liver detoxify?

Optimal performance of the liver is integral to preventing disease

Toxins enter the body in food, water, through the skin and by inhalation. These toxins – such as pesticides, pharmaceutical drugs, chemicals and water-borne pollutants – end up in our bloodstream, and our liver filters the blood to remove them. Toxins are also created by biochemical reactions in the body. Toxins affect us in many ways, from drunkenness caused by alcohol, to the side effects of certain medication. The liver transforms fat-soluble toxins into a water-soluble form. This enables them to be released through the kidneys for elimination in urine, or into bile for elimination through the colon. Enzymes chemically break down toxins that have been absorbed through the intestines. The toxins are either neutralised, or converted into a more chemically active form which is then neutralised, to be safely excreted. A healthy liver will manufacture approximately one litre (1.75 pints) of bile per day to transport toxins out of the body. If the liver is sluggish, toxins can build up, causing inflammation and oxidative stress. Toxins that are not eliminated return to the bloodstream and are eventually stored in fatty tissues where they pose less of an immediate threat. In the longer term, however, the slow release of these toxins back into the bloodstream can lead to a number of diseases.

Toxins come in many shapes and sizes and must all be processed by the liver for excretion

The liver at work



Sinusoid
This blood vessel carries nutrients and oxygen from the portal and hepatic arteries past the hepatocytes and back to the central vein.

Bile duct
Bile is largely produced by breaking down cholesterol, bile salts, water and bilirubin – which is a product of red blood cells.

Hepatocyte
Hepatocytes manufacture bile and secrete it into small channels that drain into the bile ducts.

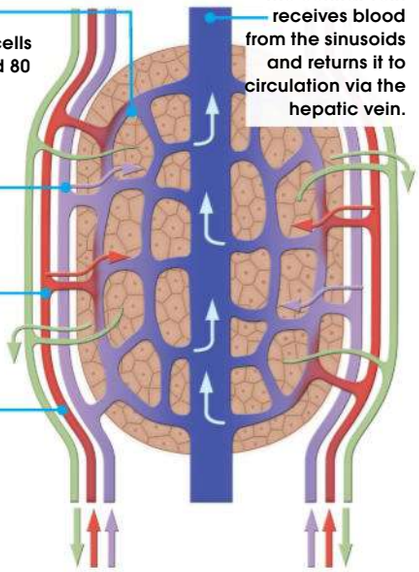
Kupffer cell
Kupffer cells partly line the sinusoids and destroy microbes and dead cells.

White blood cell
These cells are part of the immune system and help our bodies fight off infection.

Fat-storing cell
These cells contain fat that regulates local blood flow to the hepatocytes. They play a key role in repairing cells in the liver when they're damaged.

Red blood cell
These cells carry oxygen to the body's tissues. They contain iron-rich haemoglobin, which is the pigment that makes blood red.

A liver lobule close up



Central vein
The central vein receives blood from the sinusoids and returns it to circulation via the hepatic vein.

Hepatocytes
Hepatocytes are the predominant cells of the liver, making up an estimated 80 percent of the organ's mass. They perform metabolic and endocrine functions as well as detoxification.

Branch of portal vein
This vein delivers nutrient-rich blood for use by the hepatocytes.

Branch of hepatic artery
This artery delivers oxygen-rich blood for use by the hepatocytes.

Branch of bile duct
This is a long tube-like structure that carries bile, secreted by the liver and needed for digestion, towards the intestine.

How the pancreas works

Learn how the workhorse of the digestive system helps to break down food and control our blood sugar levels

The pancreas is a pivotal organ within the digestive system. It sits inside the abdomen, behind the stomach and the large bowel, adjacent to the spleen. In humans, it has a head, neck, body and tail. It is connected to the first section of the small intestine, the duodenum, by the pancreatic duct, and to the bloodstream via a rich network of vessels. When it comes to the function of the pancreas, it is best to think about the two types of cell it contains: endocrine and exocrine.

The endocrine pancreas is made up of clusters of cells called islets of Langerhans, which in total contain approximately 1 million cells and are responsible for producing hormones. These cells include alpha cells, which secrete glucagon, and beta cells which generate insulin. These two hormones have opposite effects on blood sugar levels throughout the body: glucagon increases glucose levels, while insulin decreases them. The cells here are all in contact with capillaries, so hormones that are produced can be fed directly into the bloodstream. Insulin secretion is under the control of a negative-feedback loop; high blood sugar will lead to insulin secretion, which then lowers blood sugar with subsequent suppression of insulin. Disorders of these cells (and thus alterations of the hormone levels) can lead to many serious conditions, including diabetes. The islets of Langerhans are also responsible for producing other hormones, like somatostatin, which governs nutrient absorption among many other things.

The exocrine pancreas, meanwhile, is responsible for secreting digestive enzymes. Cells are arranged in clusters called acini, which flow into the central pancreatic duct. This leads into the duodenum – part of the small bowel – to come into contact with and aid in the digestion of food. The enzymes secreted include proteases (to digest protein), lipases (for fat) and amylase (for sugar/starch). Secretion of these enzymes is controlled by a series of hormones, which are released from the stomach and duodenum in response to the stretch from the presence of food.

Anatomy of the pancreas

It might not be the biggest organ but the pancreas is a key facilitator of how we absorb nutrients and stay energised

Tail of the pancreas
This is the end portion of the organ and is positioned close to the spleen.

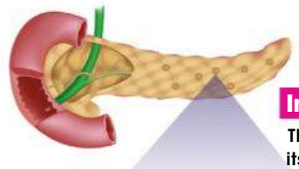
Blood supply
The pancreas derives its blood supply from a variety of sources, including vessels running to the stomach and spleen.

Does the pancreas vary in humans and animals?

Every vertebrate animal has a pancreas of some form, meaning they are all susceptible to diabetes too. The arrangement, however, varies from creature to creature. In humans, the pancreas is most often a single structure that sits at the back of the abdomen. In other animals, the arrangement varies from two or three masses of tissue scattered around the abdomen, to tissue interspersed within the connective tissue between the bowels, to small collections of tissue within the bowel mucosal wall itself. One of the other key differences is the number of ducts that connect the pancreas to the bowel. In most humans there's only one duct, but occasionally there may be two or three – and sometimes even more. In other animals, the number is much more variable. However, the function is largely similar, where the pancreas secretes digestive enzymes and hormones to control blood sugar levels.

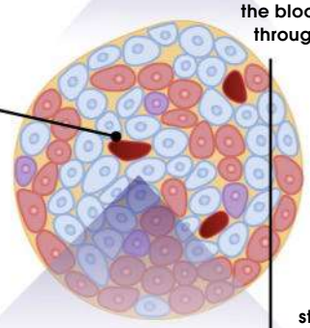
What brings on diabetes?

Diabetes is a condition where a person has higher blood sugar than normal. It is either caused by a failure of the pancreas to produce insulin (ie type 1, or insulin-dependent diabetes mellitus), or resistance of the body's cells to insulin present in the circulation (ie type 2, or non-insulin-dependent diabetes mellitus). There are also other disorders of the pancreas. Inflammation of the organ (ie acute pancreatitis) causes severe pain in the upper abdomen, forcing most people to attend the emergency department as it can actually be life threatening. In contrast, cancer of the pancreas causes the individual gradually worsening pain, which can commonly be mistaken for various other ailments.



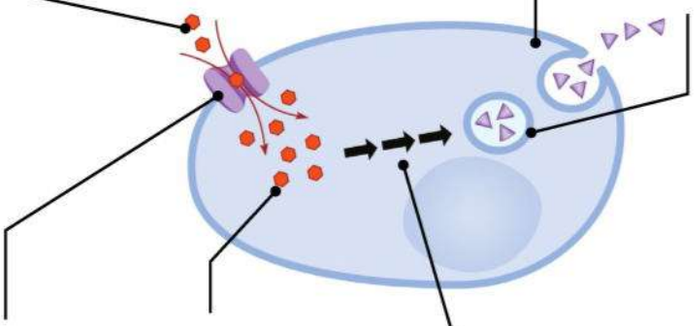
Beta cells
It is the beta cells within the islets of Langerhans that control glucose levels and amount of insulin secretion.

Insulin released
The vesicle releases its stored insulin into the blood capillaries through exocytosis.



High glucose
When the levels of glucose within the bloodstream are high, the glucose wants to move down its diffusion gradient into the cells.

Calcium effects
The calcium causes the vesicles that store insulin to move towards the cell wall.



GLUT2
This is a glucose-transporting channel, which facilitates the uptake of glucose into the cells.

Depolarisation
The metabolism of glucose leads to changes in the polarity of the cell wall and an increase in the number of potassium ions.

Calcium channels
Changes in potassium levels cause voltage-gated calcium channels to open in the cell wall, and calcium ions to flow into the cell.

© Corbis; Süleyman Habib

The human pelvis

Linking our upper and lower body, this basin-shaped complex of bones is essential for getting around

The pelvis is an essential part of the skeleton that acts as a junction between the abdomen and the legs. It consists of eight key structures: the sacrum, ilium, ischium, pubic bone, pubic symphysis, obturator foramen, acetabulum and coccyx, which are laid out symmetrically. Together these make up the bony pelvis.

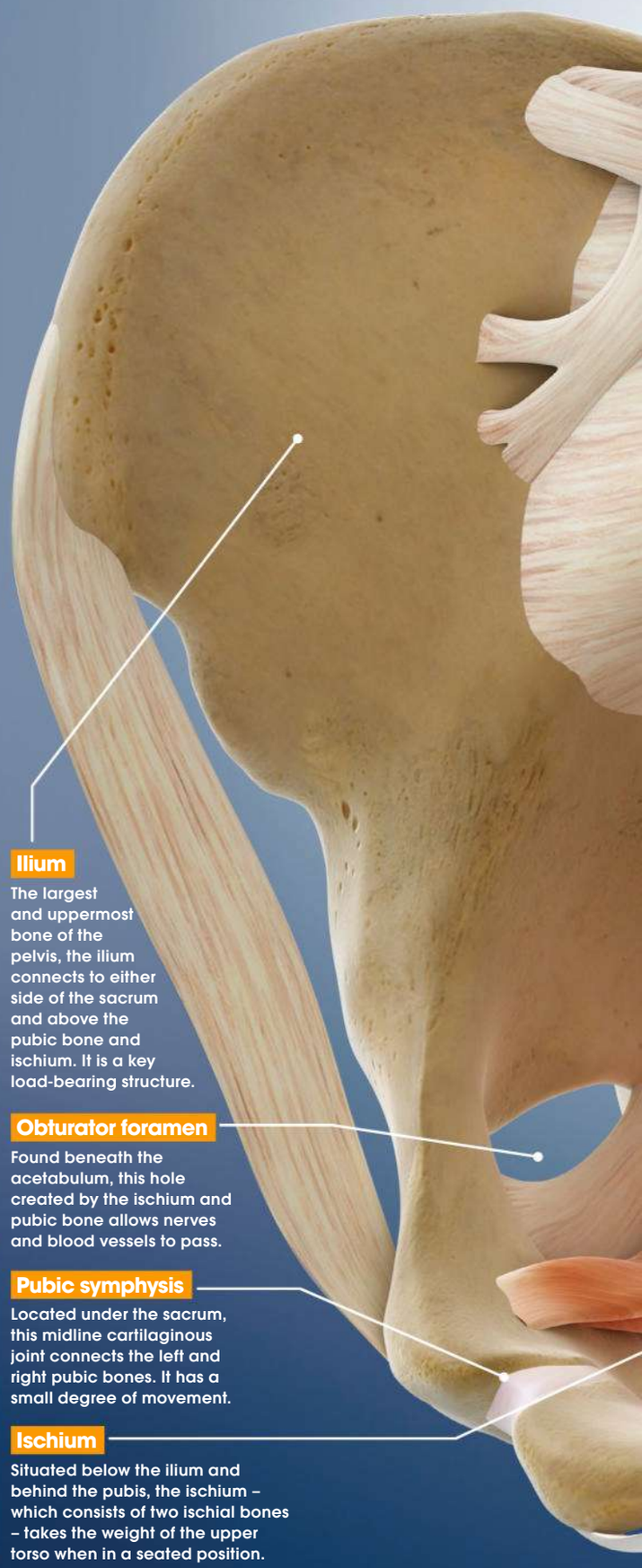
The role of the pelvis is threefold. Firstly, it serves as a connecting mechanism between the torso and the legs. Secondly, it is a vital support and balance structure for the upper body. And thirdly it provides a protective, containing cradle for the intestines, bladder and internal sex organs.

The pelvis – technically referred to as the pelvic girdle in this context – consists of a pair of hipbones connected to the base of the vertebral column. Each hipbone is formed from the fusing of three smaller bones (the ilium, ischium and pubic bone) that, when combined, link the base of the spine (the sacrum) to the lower limbs via the acetabula – the cup-shaped cavities into which the femurs fit via ball-and-socket joints. The pelvic girdle, when fully formed, resembles a roughly cylindrical basin, or the pelvic cavity, perforated on the underside with two main sets of holes. These are the aforementioned acetabula, as well as the obturator foramina, the former receiving the thighbones (femurs) and the latter allowing for the passage of nerves and blood vessels between the torso and the lower body.

Interestingly, in infants the pelvis is a far narrower structure than it is at full maturity, offering little – if any – support. This eventually changes as we grow, with the pelvis broadening and tilting under the influence of increased walking and standing.

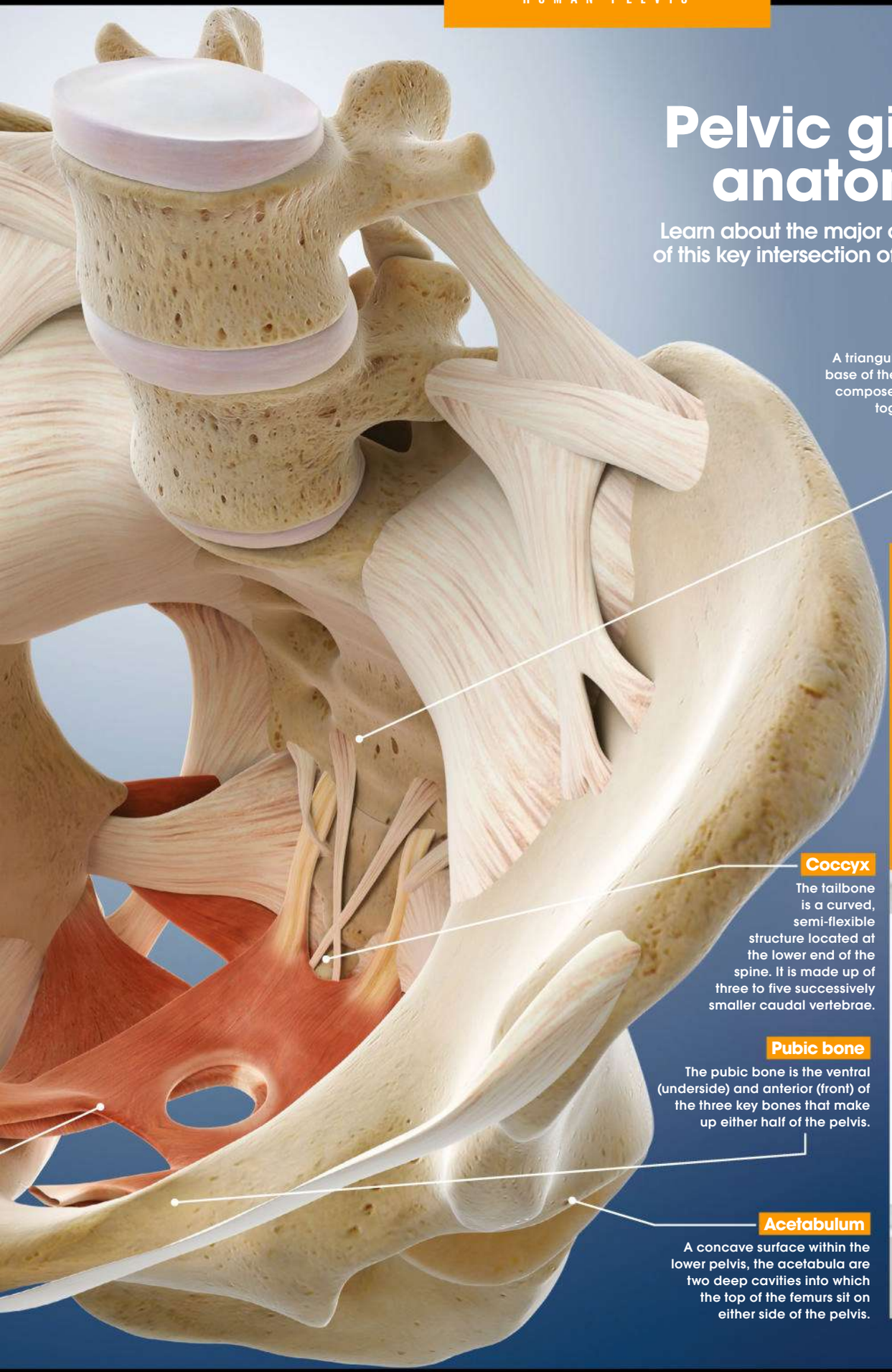
When it is fully formed, the human pelvic skeleton can comprise more than ten bones, with the number determined by the composition of the individual's tailbone (coccyx). This structure is composed of three to five successively smaller caudal vertebrae located at the base of the sacrum.

The female pelvis tends to mature between 11 and 15 years of age, while the male pelvis may take 17 years to fully develop



Pelvic girdle anatomy

Learn about the major components of this key intersection of the skeleton



Sacrum

A triangular-shaped bone that sits at the base of the vertebral column. It is typically composed of five vertebrae, which fuse together during childhood.

Coccyx

The tailbone is a curved, semi-flexible structure located at the lower end of the spine. It is made up of three to five successively smaller caudal vertebrae.

Pubic bone

The pubic bone is the ventral (underside) and anterior (front) of the three key bones that make up either half of the pelvis.

Acetabulum

A concave surface within the lower pelvis, the acetabula are two deep cavities into which the top of the femurs sit on either side of the pelvis.

Male vs female

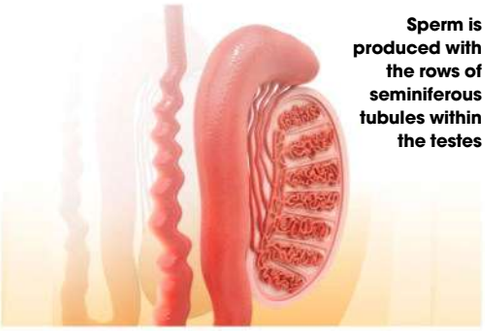
Differences between the male and female pelvis are numerous and stem, primarily, from the female's reproductive system. For example, the female pelvic basin is broader than the male equivalent, the pubic symphysis short and the pubic bones connect in a wider angle with each other. In addition, the coccyx has a greater degree of movement and the two acetabula are spaced farther apart. All together these allow a rounded and spacious birth canal – which hasn't been an evolutionary priority in the male of the species.

© Thinkstock; SPL

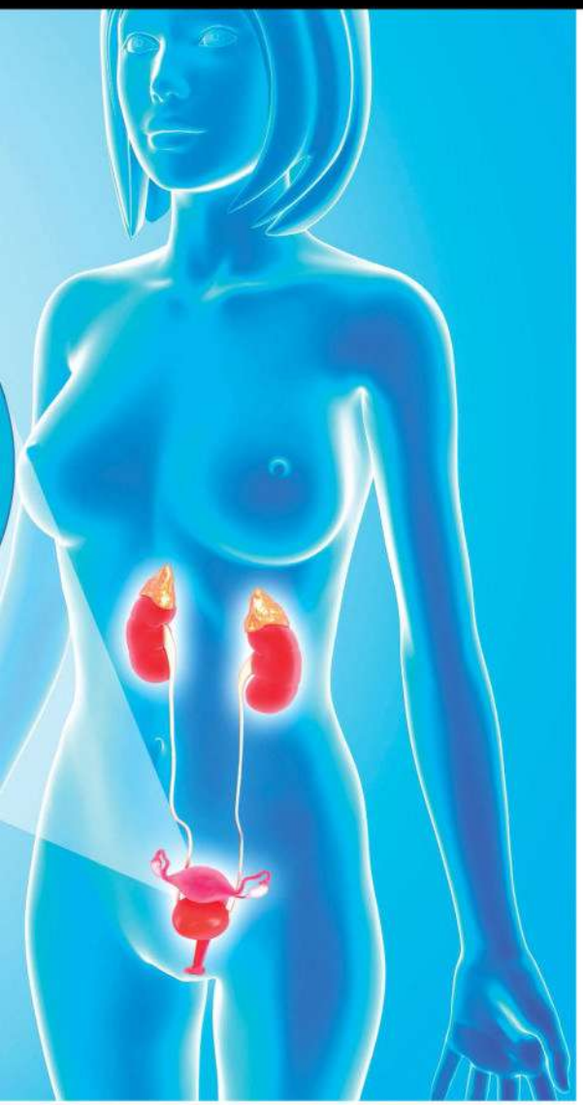
The human reproductive system

Meet the many organs and glands that make it possible for people to have babies

A person's reproductive system is made up of a collection of organs and a network of hormone releasing glands that function for the purpose of sexual reproduction. Both male and female reproductive systems are divided into three sections: the gonads, internal and external genitalia. The gonads of each system produce reproductive cells, called gametes. For people assigned male at birth (AMAB) the gonads are the testes and amongst those assigned female at birth (AFAB) the gonads are the ovaries. The rest of the system's glands and organs are collectively known as genitalia. Each system is governed by chemical messengers called hormones, which dictate how and when reproductive cells are made and when the body is ready to make a baby.



Sperm is produced with the rows of seminiferous tubules within the testes



The male reproductive system

How the body manufacturers and transports sperm

From the external appendage of the penis and its testicular companions, to the internal bladder-hugging prostate gland, both the internal and external portions of the male reproductive system are designed to carry out three main functions; the creation and storage of productive cells, the release of vital hormones and for sexual pleasure.

At the start of the male reproductive system are the oval-shaped glands called the testes, also referred to as the testicles. The predominant function of the testes is to act as a factory for the production of reproductive cells called sperm. These sperm factories take their orders from a hormone, which is also produced in the testes, called testosterone.

When a testosterone production order is received by a cluster of tubes within the testes called seminiferous tubules, they begin assembling the tadpole-like sperm cells. Along with turbo-charging the testes sperm production, testosterone also triggers the body's production of facial, pubic and body hair and plays an important role in maintaining the body's bone density and distribution of fat.

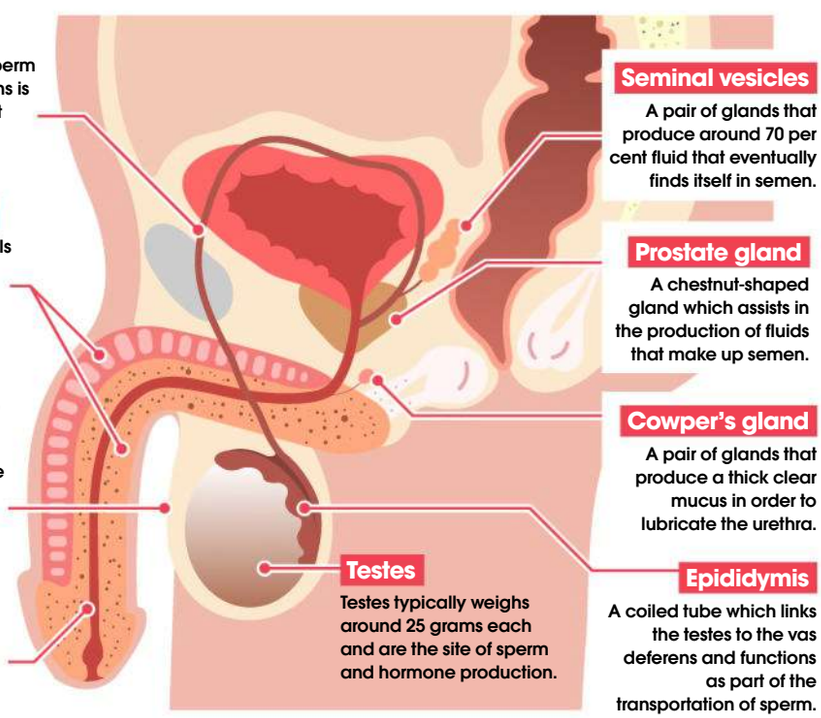
Once the cells are fully formed, the sperm continues on the reproductive production line to a muscular holding pen, called the epididymis, where it is stored and awaits to be dispatched. To produce healthy sperm cells, the testes need to maintain a temperature of around 34 degrees Celsius. This is why the testes are found on the outside of the body because its natural internal temperature of 37 degrees Celsius is too hot for healthy cell production. The testes can continue producing sperm cells for the duration of their lives. However, the number of strong swimmers begins to decline at around 40 years of age. Some studies have shown that after 39 years of age, sperm production declines up to 23 per cent each year.

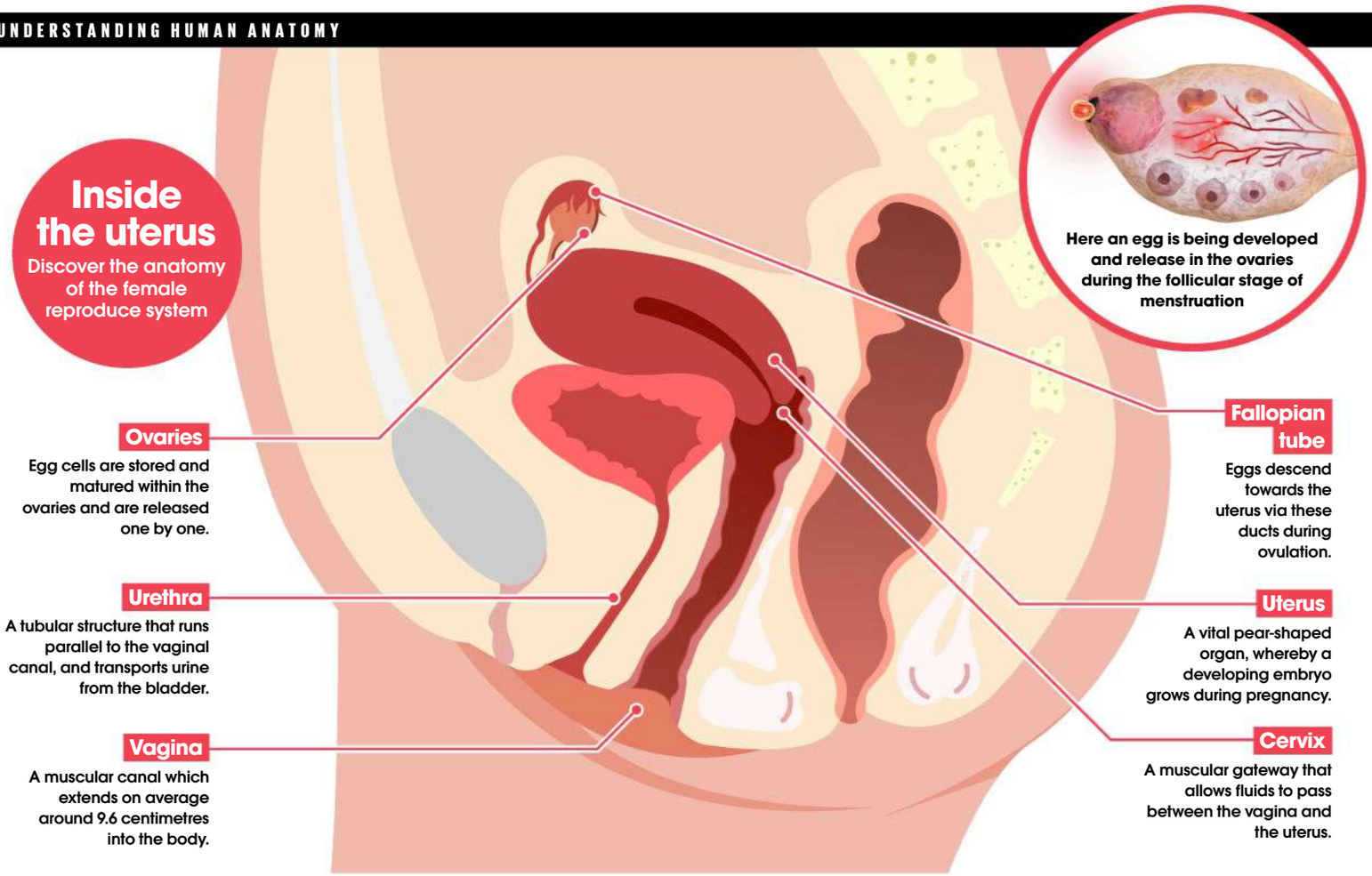
When the reproductive system is ready to release the sperm, it is combined with lubricating fluid which is produced in the glandular department, such as the prostate gland, to become what's collectively known as semen. Semen is then carried through a tubular structure called the urethra, from the internal genitalia and through the penis. The urethra is also responsible for the transportation of urine, but a small muscular gate between the connection to the bladder and the testes prevents both fluids from passing through at the same time.

The penis is made up of three column-like chambers; the two largest are called the corpus cavernosum and the spongy corpus spongiosum which surrounds the urethra. During sexual arousal, the chambers of the corpus cavernosum fill with blood causing the to penis become erect. When the head of the penis, known as the glans, is stimulated, the prostate and penile chambers contract forcing the semen from the body, in a process called ejaculation.

Male mechanics

How the male produce system functions and produces sperm





The female reproductive system

The journey from egg to embryo and the organs that are built for baby making

Like its male counterpart, the female reproductive system also consists of both external and internal components. The external female genitalia, commonly known as the vulva, consists of a sensory organ called the clitoris, lubricating glands, and folds of skin known as the labia majora and labia minora around the vaginal opening. Internally, a complex system of glands and organs work together to not only produce female sexual cells (commonly called eggs), but also provide an environment for a developing baby to grow.

At the start of the reproductive system are a pair of almond-shaped organs called the ovaries.

In the same way that the male testes spend their time manufacturing sperm cells, their female counterparts produce premature egg cells, called oocytes. This process, known as oogenesis, occurs long before a person is born. This means that at the point of birth, the ovaries hold all the egg cells that a person will ever have, which is between one to two million oocytes. However, at the point of puberty, this egg supply is diminished to about 25 per cent.

During a monthly menstrual cycle, egg cells mature within the ovary and are released into connecting muscular ducts called the fallopian tubes. It's during its descent through the fallopian tubes that eggs may encounter sperm cells following intercourse and become fertilised.

Much like the testes release testosterone, the ovaries aren't just a coop for eggs but also release vital hormones called oestrogen and progesterone. As well as regulating the female reproductive system, oestrogen helps regulate several other processes in the body, such as blood sugar levels, collagen production and brain function. Progesterone, on the other hand, has one main focus, letting the rest of the body know when an egg has been fertilised and there's a baby on the way.

At the point of fertilisation, a fertilised egg called an embryo, will attach to the lining of a hollow organ called the uterus, also known as the womb. The uterus's main role within the reproductive system is to create a safe environment for developing embryos. During the nine months of pregnancy, the uterus will expand and increase the thickness of its lining to accommodate a growing foetus.

At the neck of the uterus is a donut-shaped organ called the cervix. Along with controlling the fluid that travels between the two, the cervix acts as a gateway for a growing baby. During pregnancy, the cervix gradually softens until the baby is ready to be born and the cervical gateway can be easily opened as the baby descends into a muscular canal called the vagina.

The vagina acts as a passageway between the external vulva and cervix for sperm to enter during sexual intercourse and for menstruation and the baby to exist. To keep the vagina well lubricated, the epithelial cells that line it secrete a fluid and a self-cleaning discharge. This discharge is packed full of helpful bacteria and mucus, that keep the the vagina at the current pH level and fight bad bacteria which might cause infection.

The menstrual cycle

How the body prepares for pregnancy each month

Every 28 days, the female reproductive system completes a single menstrual cycle. The menstrual cycle is divided into four stages: menstruation, the follicular phase, ovulation and the luteal phase.

Menstruation signals the start of a new cycle by discharging blood from the vagina, commonly known as a period. The source of this blood mostly comes from the lining of the uterus called the endometrium. In preparing for an embryo to attach to the endometrium, the lining thickens and increases its hormone production. If a released egg finds itself unfertilised, it is discarded by the body and washed away along with the endometrium.

"These hormones send an alert to the uterus that there is a potential embryo on the way"

After a period of two to seven days, menstruation ceases. However, the second follicular phase has already been kicked into action. For up to the first 21 days of the cycle, follicles in an ovary begin to develop egg cells, but typically only one will grow to maturity.

Ovulation is the next and shortest stage in the menstrual cycle and typically only lasts for between 12 and 24 hours. During this time, a single egg is released from one of the ovaries, which alternates with each cycle and passes down a fallopian tube. While the egg waits to be fertilised, the last luteal phase in the cycle causes the ovaries to release potent hormones called progesterone. These hormones send an alert to the uterus that there is a potential embryo on the way and it begins to thicken the lining on its walls, as well as increase the production of mucus on the cervix to prevent harmful bacteria from finding its way inside the uterus. If no such embryo attaches to uterine lining, the menstruation cycle starts again and menstruation commences.

~37.5 years

The average amount of years a person menstruates

60 millilitres

The amount of blood lost on average during menstruation

0.3 degrees Celsius

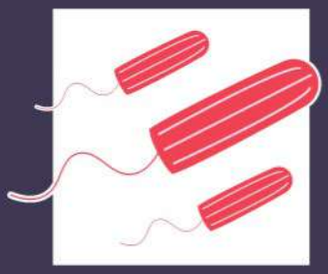
The body experiences a slight increase in temperature during ovulation

11 to 20 eggs

At the start of the follicular phase many eggs start to develop but only one matures

60%

More than half of the people menstruate experience mild cramps



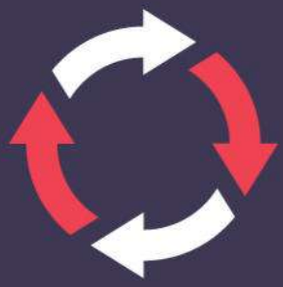
First tampon invented in by American physician Earle Haas in

1931

A person will spend the equivalent of

6.5

years of their life menstruating



On average menstrual cycles occur

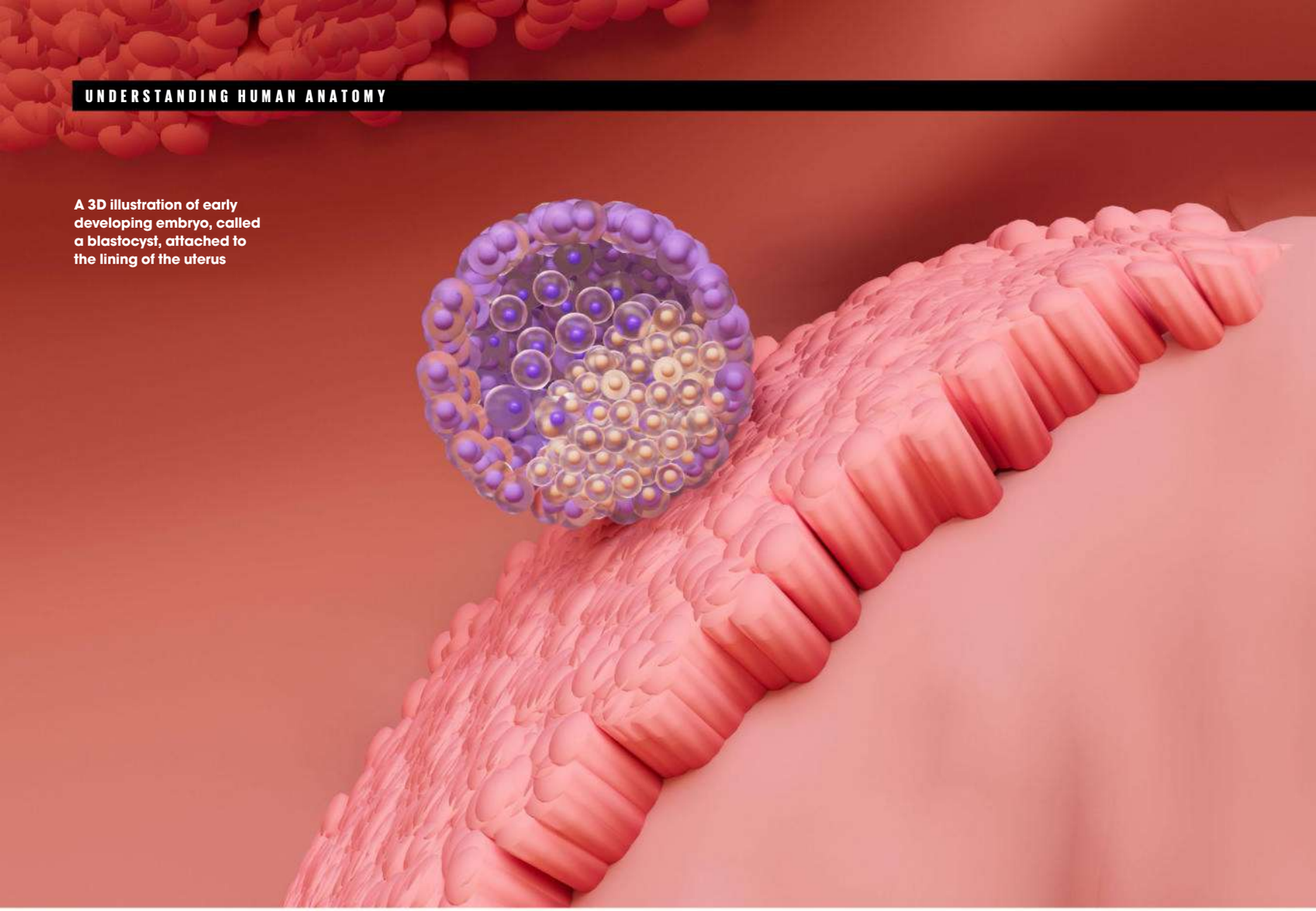
13

times per year

Around

26%

of the global population menstruate



A 3D illustration of early developing embryo, called a blastocyst, attached to the lining of the uterus

How babies are made

The fusion of sex cells that begins the great journey of pregnancy

Humans reproduce by sexual reproduction, whereby the genetic information of two people is mixed. The female set of genetic instructions comes from eggs, while sperm provide the males genetic contribution.

Both the egg and sperm hold instructions encoded by deoxyribonucleic acid (DNA), which contains all the information needed to form a functional human body. The cells' DNA is wrapped up tightly into large structures called chromosomes. Both the egg cell and the sperm cell carry 23 chromosomes, which once aligned in an embryo will form 23 pairs that will be carried by every somatic cell in a mature human body. Two of these chromosomes form a pair known as sex chromosomes, as they define the sex of the baby during development. Every egg cell carries an X chromosome, and a sperm cell can carry either an X or a Y chromosome.

Females are encoded by a combination of XX, and males by a combination of XY. Our genetic sex will be sealed the very moment that our two sets of chromosomes first meet during the fertilisation process.

Did you know?
Between the ages of 12 and 52, a woman will have around 480 periods

The fusion between a sperm and egg cell's DNA marks the beginning of embryo development, and once it has found its home in the nourishing lining of the uterine wall, the embryo undergoes a monumental growth spurt. It transforms from a mere bundle of cells into a foetus, acquiring a heart, brain, jaw, fingers and toes. Within the first 12 weeks of pregnancy, the foetus boasts a full complement of organs. This incredible metamorphosis is guided on a cellular level by genetic instructions encoded within the DNA and by external environmental signals. These signals tell the cells how to interact with one another, where to migrate, how to divide and when to die to make way for new cells. This allows a swarm of microscopic cells to differentiate and develop into something not only gargantuan in size but also in complexity: a fully formed human baby.

"The fusion between a sperm and egg cell's DNA marks the beginning of embryo development"

The genesis of life

The steps that bring together DNA from parents and initiate pregnancy

X meets Y, or X

Following fertilisation, the two cells combine their DNA. Each cell carries a single copy of 23 chromosomes, which are large packages of DNA.

Union

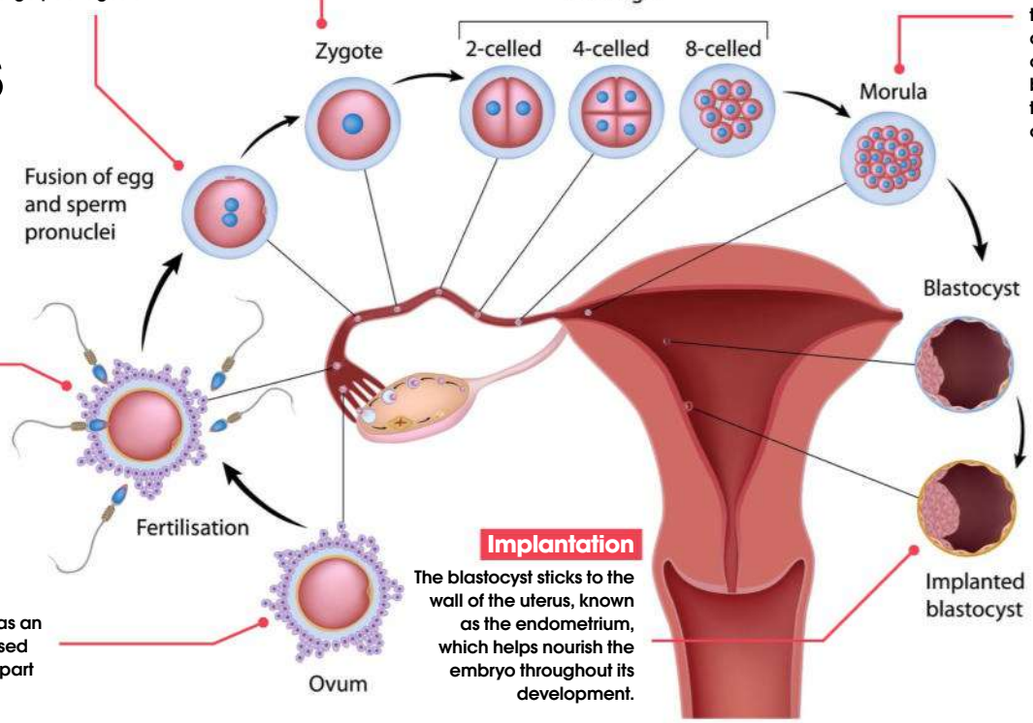
A fertilised cell with a full complement of 23 pairs of chromosomes forms a zygote, which migrates through the fallopian tube towards the uterus.

Cleavage

As the fertilised cell migrates towards the uterus it undergoes cleavage, dividing from a single cell into a connected cluster of cells called blastomeres.

Morula

The berry-like configuration of blastomeres continues to divide, becoming a morula. During these latter divisions the cells commit to becoming either the embryo or placenta.



Fertilisation

For 12 to 24 hours after it's released, an egg can be fertilised by a sperm cell that has successfully traversed the fallopian tube.

Ovulation

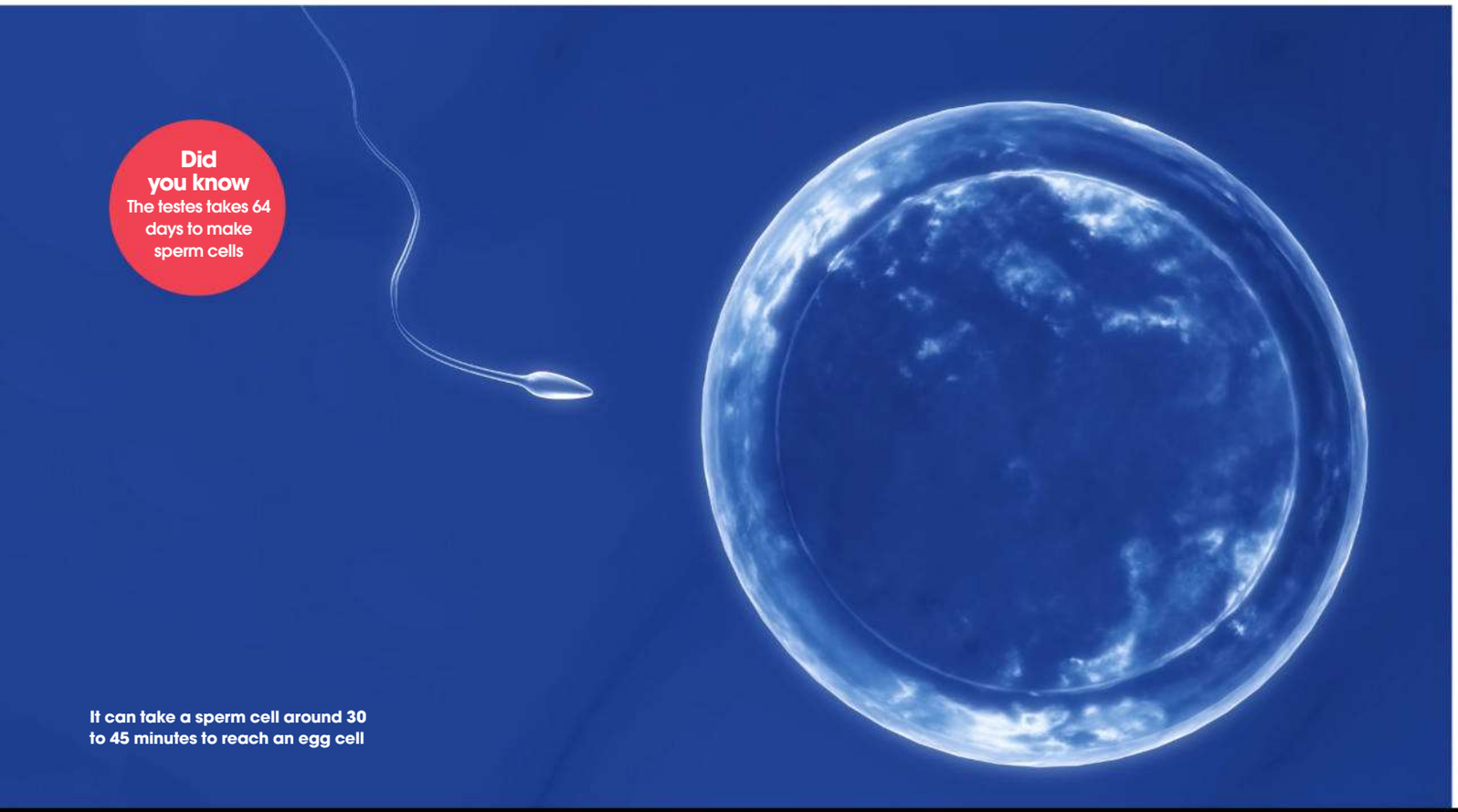
A mature egg cell, known as an ovum, is periodically released from a female's ovaries as part of the menstrual cycle.

Implantation

The blastocyst sticks to the wall of the uterus, known as the endometrium, which helps nourish the embryo throughout its development.

Blastocyst

A cavity of fluid builds between the inner cell mass, which will become the embryo, and the outer cells, which will help form the nourishing placenta.



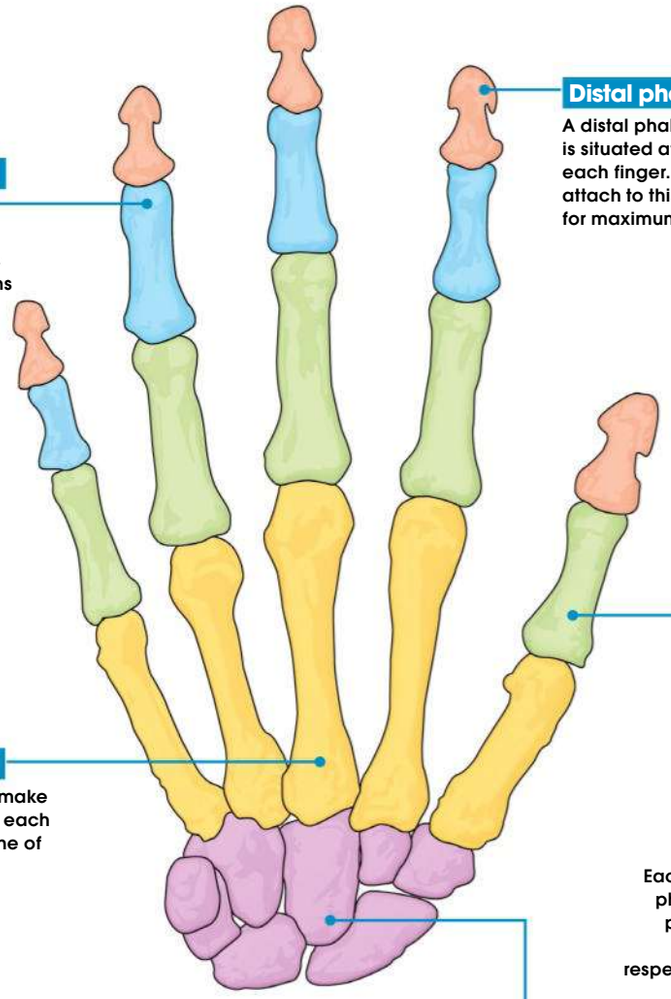
Did you know
The testes takes 64 days to make sperm cells

It can take a sperm cell around 30 to 45 minutes to reach an egg cell

© Alamy / Getty / Science Photo Library

The human hand

We take our hands for granted, but they are actually quite complex and have been crucial in our evolution



The human hand is an important feature of the human body, which allows individuals to manipulate their surroundings and also to gather large amounts of data from the environment that the individual is situated within. A hand is generally defined as the terminal aspect of the human arm, which consists of prehensile digits, an opposable thumb, and a wrist and palm. Although many other animals have similar structures, only primates and a limited number of other vertebrates can be said to have a 'hand' due to the need for an opposable thumb to be present and the degree of extra articulation that the human hand can achieve. Due to this extra articulation, humans have developed fine motor skills allowing for much increased control in this limb. Consequently, we see improved ability to grasp and grip items and development of skills such as writing.

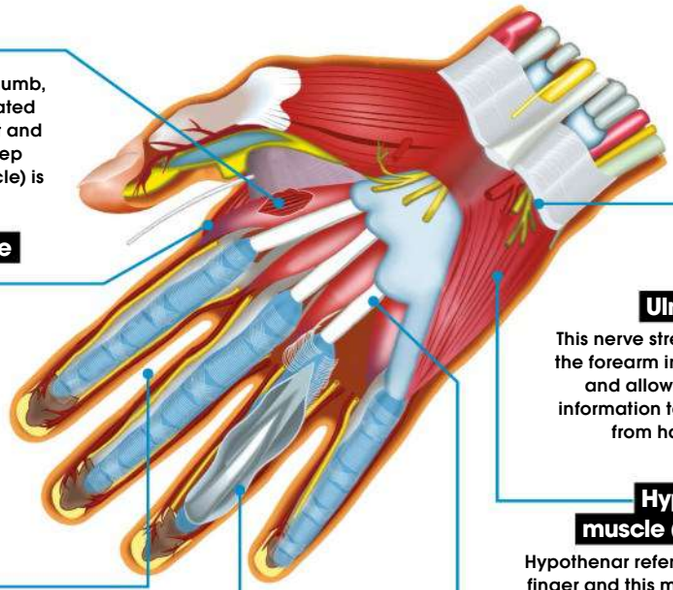
A normal human hand is made up of five digits, the palm and wrist. It consists of 27 bones, tendons, muscles and nerves, with each fingertip of each digit containing numerous nerve endings, making the hand a crucial area for gathering information from the environment using one of man's most crucial five senses: touch. The muscles interact together with tendons in order to allow fingers to bend, straighten, point and, in the case of the thumb, rotate. However, the hand is an area that sees many injuries due to the number of ways we use it, with one in ten injuries in A&E being hand related, and there are also several disorders that can affect the hand development whilst still in the womb, such as polydactyly, where an individual is born with extra digits, which are often still in perfect working order.

Bones in the hand

The human hand contains 27 bones, and these divide up into three distinct groups: the carpals, metacarpals and phalanges. These also then break down into a further three different groups: the proximal phalanges, the intermediate phalanges and then the distal phalanges. Eight bones are situated in the wrist and these are collectively called the carpals. The metacarpals, which are situated in the palm of the hand account for a further five out of the 27, and each finger has three phalanges, the thumb only has two. Intrinsic muscles and tendons control movement of the digits and hand, and attach to extrinsic muscles that extend further up into the arm, flexing the digits.

Muscles and other structures

The movements and articulations of the hand and by the digits are not only controlled by tendons, but also by the two muscle groups situated within the hand and wrist. These are the extrinsic and intrinsic muscle groups, so named as the extrinsics are attached to muscles which extend into the forearm, whereas the intrinsics are situated within the hand and wrist. The flexors and extensors, which make up the extrinsic muscles, use either exclusively tendons to attach to digits they control (flexors) or a more complex mix of tendons and intrinsic muscles to operate (extensors). These muscles will contract in order to cause digit movement, and flexors and extensors work in a pair to complement each to straighten and bend digits. The intrinsic muscles are responsible for aiding all extrinsic muscle action and any other movements in the digits and have three distinct groups; the thenar and hypothenar (referring to the thumb and little finger respectively), the interossei and the lumbrical.



Thenar space
Thenar refers to the thumb, and this space is situated between the first digit and thumb. One of the deep flexors (extrinsic muscle) is located in here.

Interossei muscle (intrinsic)
This interossei muscle sits between metacarpal bones and will unite with tendons to allow extension using extrinsic muscles.

Arteries, veins and nerves
These supply fresh oxygenated blood (and take away deoxygenated blood) to hand muscles.

Insertion of flexor tendon
This is where the tendon attaches the flexor muscle to the finger bones to allow articulation.

Ulnar nerve
This nerve stretches down the forearm into the hand and allows for sensory information to be passed from hand to brain.

Hypothenar muscle (intrinsic)
Hypothenar refers to the little finger and this muscle group is one of the intrinsic muscles.

Mid palmar space
Tendons and intrinsic muscles primarily inhabit this space within the hand.

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Opposable thumbs

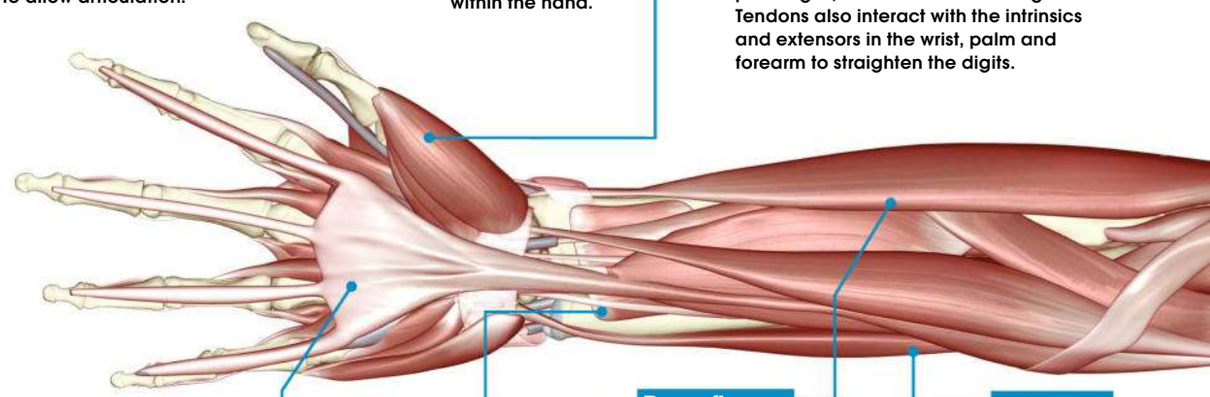
Increased articulation of the thumb has been heralded as one of the key factors in human evolution. It allowed for increased control and grip, and has allowed for tool use in order to develop among human ancestors as well as other primates. This has later also facilitated major cultural advances, such as writing. Alongside the four other flexible digits, the opposable thumb makes the human hand one of the most dexterous in the world. A thumb can only be classified as opposable when it can be brought opposite to the other digits.

Left handed or right handed?

The most common theory for why some individuals are left handed is that of the 'disappearing twin'. This supposes that the left-handed individual was actually one of a set of twins, but that in the early stages of development the other, right handed, twin died. However, it's been found that dominance of one hand is directly linked with hemisphere dominance in the brain, as in many other paired organs. Individuals who somehow damage their dominant hand for extended periods of time can actually change to use the other hand, proving the impact and importance of environment and extent to which humans can adapt.

Forearm muscles

Extrinsic muscles are so called because they are primarily situated outside the hand, the body of the muscles situated along the underside or front of the forearm. This body of muscles actually breaks down into two quite distinct groups: the flexors and the extensors. The flexors run alongside the underside of the arm and are responsible for allowing the bending of the individual digits, whereas the extensor muscles' main purpose is the reverse this action, to straighten the digits. There are both deep and superficial flexors and extensors, and which are used at any one time depends on the digit to be moved.



Tendons and intrinsics
These attach the flexor muscles to the phalanges, and facilitate bending. Tendons also interact with the intrinsics and extensors in the wrist, palm and forearm to straighten the digits.

Thenars
The intrinsic group of muscles is used to flex the thumb and control its sideways movement.

Superficial flexors
The other flexor that acts on the digits is the superior flexor, which attaches to the intermediate phalanges.

Deep flexors
The digits have two extrinsic flexors that allow them to bend, the deep flexor and the superficial. The deep flexor attaches to the distal phalanges.

Extensors
Extensors on the back of the forearm straighten the digits. Divided into six sections, their connection to the digits is complex.

© Science photo library

Inside the knee

How do our knee joints allow us to walk and run?

The knee is the largest and also one of the most complex joints in the body, allowing us bipedal humans to move around and get from point A to point B. Three different bones meet at the knee joint and work together to allow for movement and protection. At the top of the knee is the lower part of the thighbone (femur). This rotates on top of the shinbone (tibia) and the kneecap (patella), the latter of which moves in a groove between the femur and tibia. Cartilage within the knee cushions it from shock caused by motion, while ligaments prevent damage occurring to the joint in case of unusual or erratic motion. Muscles running from the hip down to the knee joint are responsible for working the knee joint and allowing our legs to bend, stretch, and ultimately allowing us to walk, run and skip.

© Science Photo Library

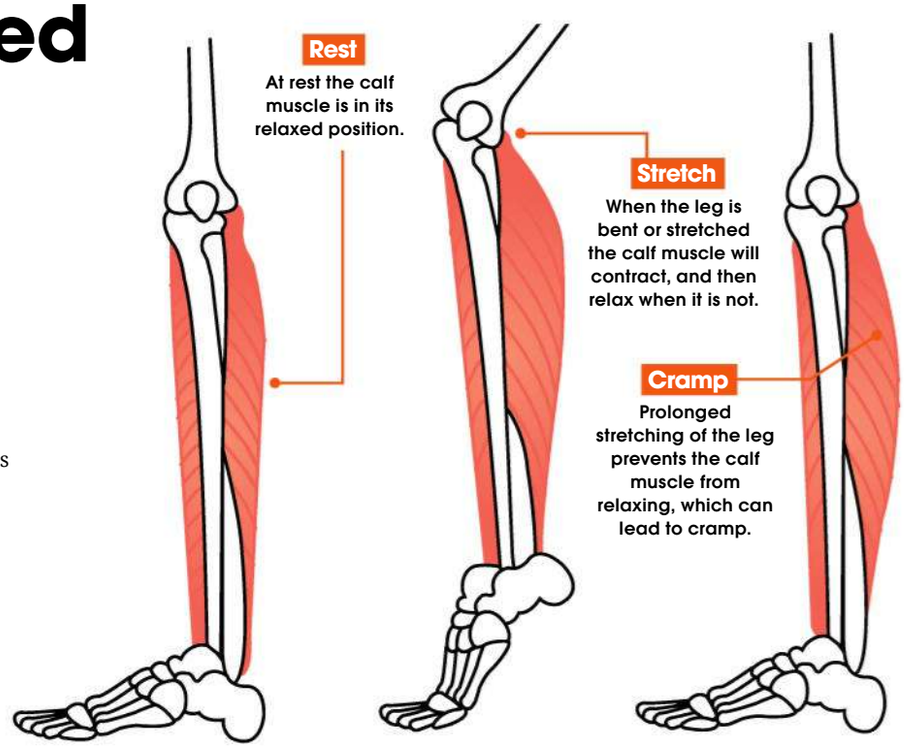
The knee structure

How does everything work in tandem to allow for movement?

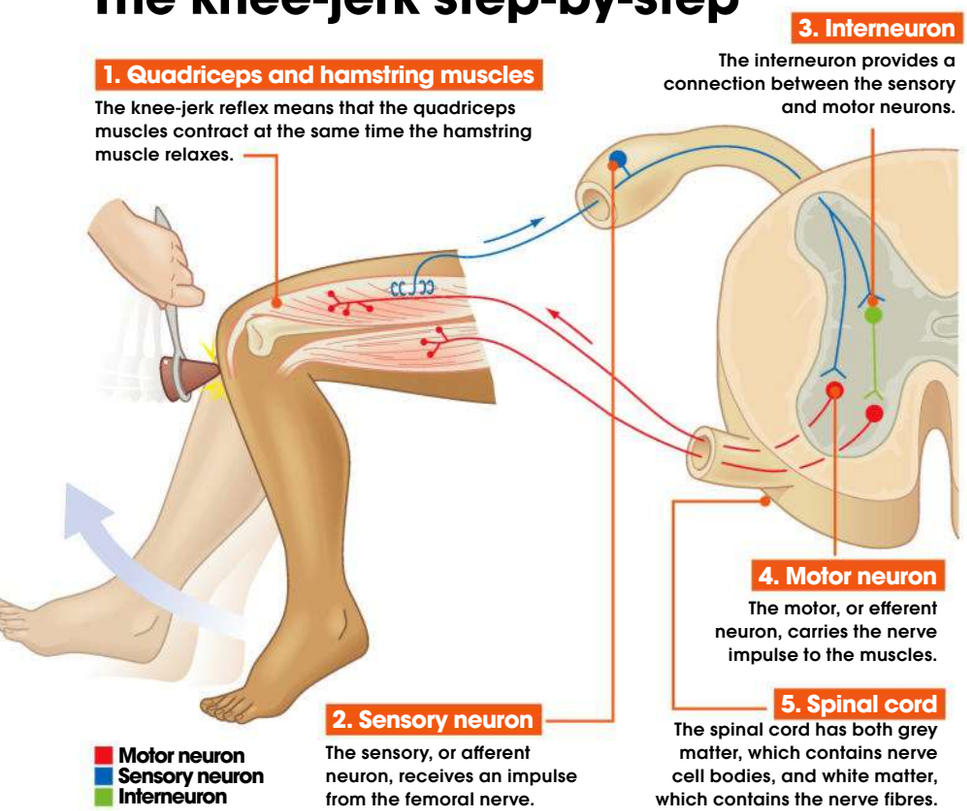
Cramp explained

Why do our muscles tense up?

Cramp is an involuntary contraction of a muscle, often in a limb such as the leg, that can cause pain and discomfort for seconds, minutes or, in extreme cases, for several hours. They are most common after or during exercise, coinciding with low blood sugar levels, dehydration and a high loss of salt from sweating. Although the full range of causes is something of a mystery due to limited research in the area, cramp is believed to be the result of muscle fatigue. If a muscle has been shortened through prolonged use but is repeatedly stimulated, it isn't able to properly relax. A reflex arc from the central nervous system to the muscle informs it to continue contracting when it is not necessary, leading to a painful spasm known as cramp as the muscle continually attempts to contract. This is why athletes pushed beyond their limits, such as football players who have to play extra time in a soccer match, and long-distance runners, will often experience this condition.



The knee-jerk step-by-step



Knee-jerk reactions explained

Why does your leg kick out when the doctor taps just below your knee?

Doctors often test the knee-jerk, or patellar reflex, to look for potential neurological problems. Lightly tapping your patellar tendon just below the kneecap stretches the femoral nerve located in your thigh, which in turn causes your thigh muscle (quadriceps) to contract and the lower leg to extend. When struck, impulses travel along a pathway in the dorsal root ganglion, a bundle of nerves in the L4 level of the spinal cord.

Reflex actions are performed independently of the brain. This allows them to happen almost instantaneously – in about 50 milliseconds in the case of the knee-jerk reflex. This reflex helps you to maintain balance and posture when you walk, without having to think about every step you take.

How do your feet work?

Feet are immensely complex structures, yet we put huge amounts of pressure on them every day. How do they cope?

The human foot and ankle is crucial for locomotion and is one of the most complex structures of the human body. This intricate structure is made up of no less than 26 bones, 20 muscles, 33 joints – although only 20 are articulated – as well as numerous tendons and ligaments.

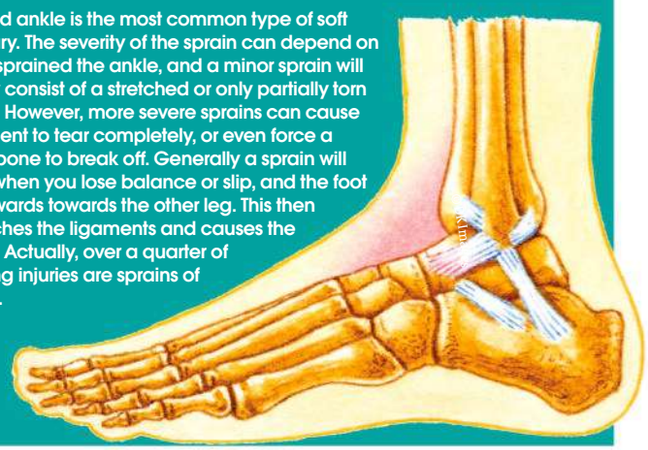
Tendons connect the muscles to the bones and facilitate movement of the foot, while ligaments hold the tendons in place and help the foot move up and down to initiate walking. Arches in the foot are formed by ligaments, muscles and foot bones and help to distribute weight, as well as making it easier for the foot to operate efficiently when walking and running.

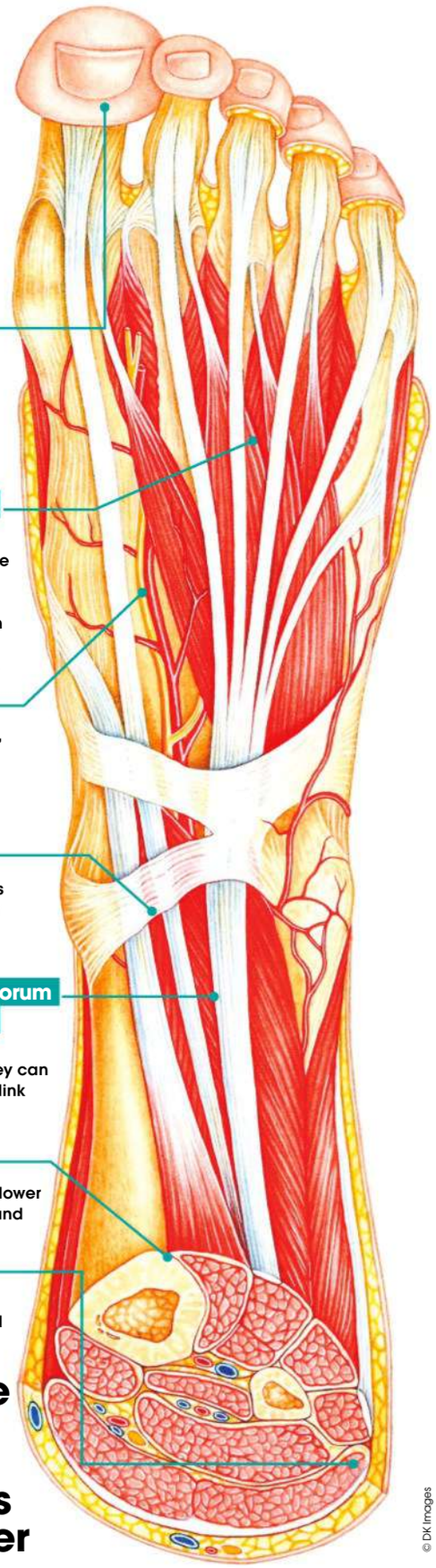
It is due to the unique structure of the foot and the way it distributes pressure throughout all aspects that it can withstand constant pressure throughout the day. One of the other crucial functions of the foot is to aid balance, and toes are a crucial aspect of this. The big toe in particular helps in this area, as we can grip the ground with it if we feel we are losing balance.

The skin, nerves and blood vessels make up the rest of the foot, helping to hold the shape and also supplying it with all the necessary minerals, oxygen and energy to help keep it moving easily and constantly.

What happens when you sprain your ankle?

A sprained ankle is the most common type of soft tissue injury. The severity of the sprain can depend on how you sprained the ankle, and a minor sprain will generally consist of a stretched or only partially torn ligament. However, more severe sprains can cause the ligament to tear completely, or even force a piece of bone to break off. Generally a sprain will happen when you lose balance or slip, and the foot bends inwards towards the other leg. This then overstretches the ligaments and causes the damage. Actually, over a quarter of all sporting injuries are sprains of the ankle.





The structure of the foot and how the elements work together

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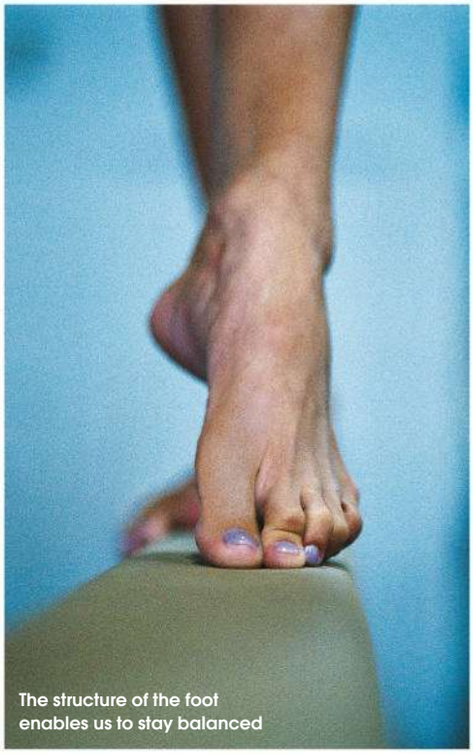


The structure of the foot enables us to stay balanced

How do we walk?

'Human gait' is the term to describe how we walk. This gait will vary between each person, but the basics are the same

2. Weight transfer
The weight will transfer fully to the foot still in contact with the ground, normally with a slight leaning movement of the body.

4. Leg swing
The lower leg will then swing at the knee, under the body, to be placed in front of the stationary, weight-bearing foot.

3. Foot lift
After weight has transferred and the individual feels balanced, the ball of the first foot will then lift off the ground, raising the thigh.

5. Heel placement
The heel will normally be the part of the foot that's placed first, and weight will start to transfer back onto this foot as it hits the ground.

1. Heel lift
The first step of walking is for the foot to be lifted off the ground. The knee will raise and the calf muscle and Achilles tendon, situated on the back of the leg, will contract to allow the heel to lift off the ground.

6. Repeat process
The process is then repeated with the other foot. During normal walking or running, one foot will start to lift as the other starts to come into contact with the ground.

Bones of the foot

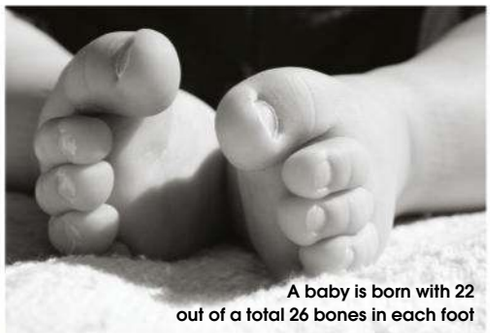
Distal phalanges
The bones which sit at the far end of the foot and make up the tips of the toes.

Proximal phalanges
These bones link the metatarsals and the distal phalanges and stretch from the base of the toes.

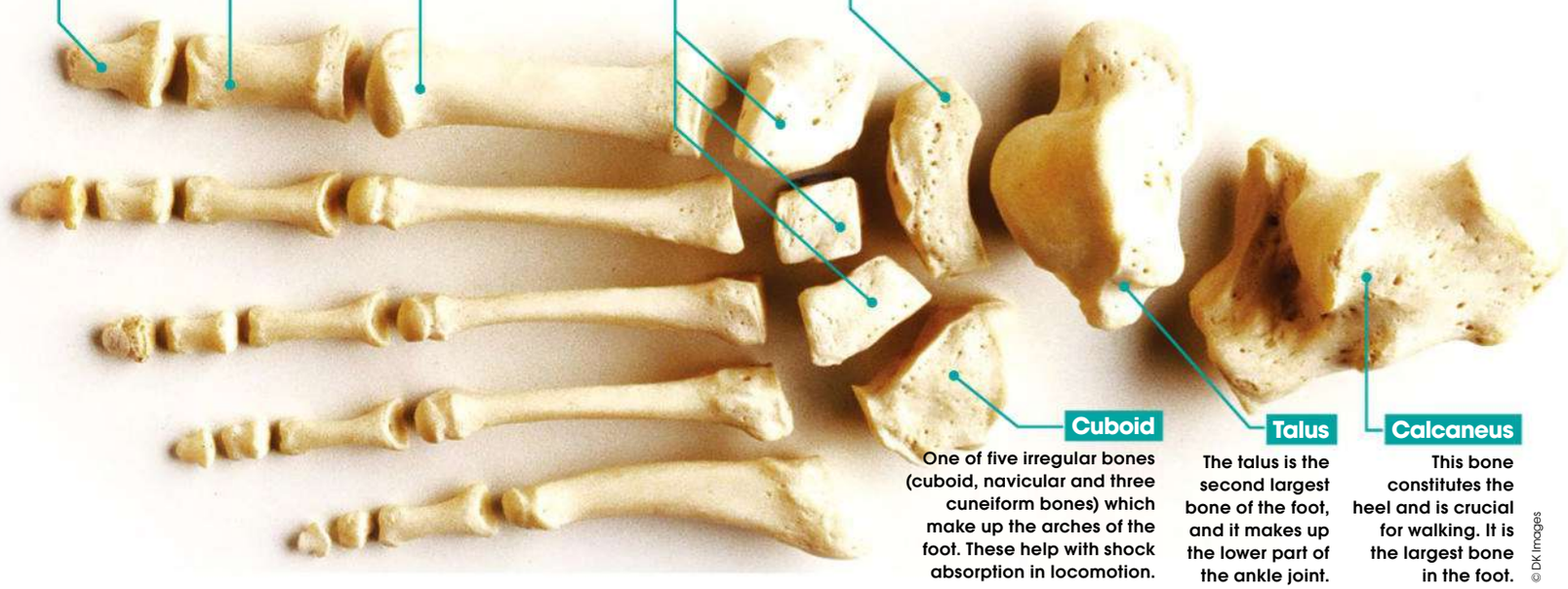
Metatarsals
The five, long bones that are the metatarsals are located between the tarsal bones and the phalanges. These are the equivalent of the metacarpals in the hand.

Cuneiforms bones (three)
Three bones that fuse together during bone development and sit between the metatarsals and the talus.

Navicular
This bone, which is so named due to its resemblance to a boat, articulates with the three cuneiform bones.



A baby is born with 22 out of a total 26 bones in each foot



Cuboid
One of five irregular bones (cuboid, navicular and three cuneiform bones) which make up the arches of the foot. These help with shock absorption in locomotion.

Talus
The talus is the second largest bone of the foot, and it makes up the lower part of the ankle joint.

Calcaneus
This bone constitutes the heel and is crucial for walking. It is the largest bone in the foot.

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Under the skin

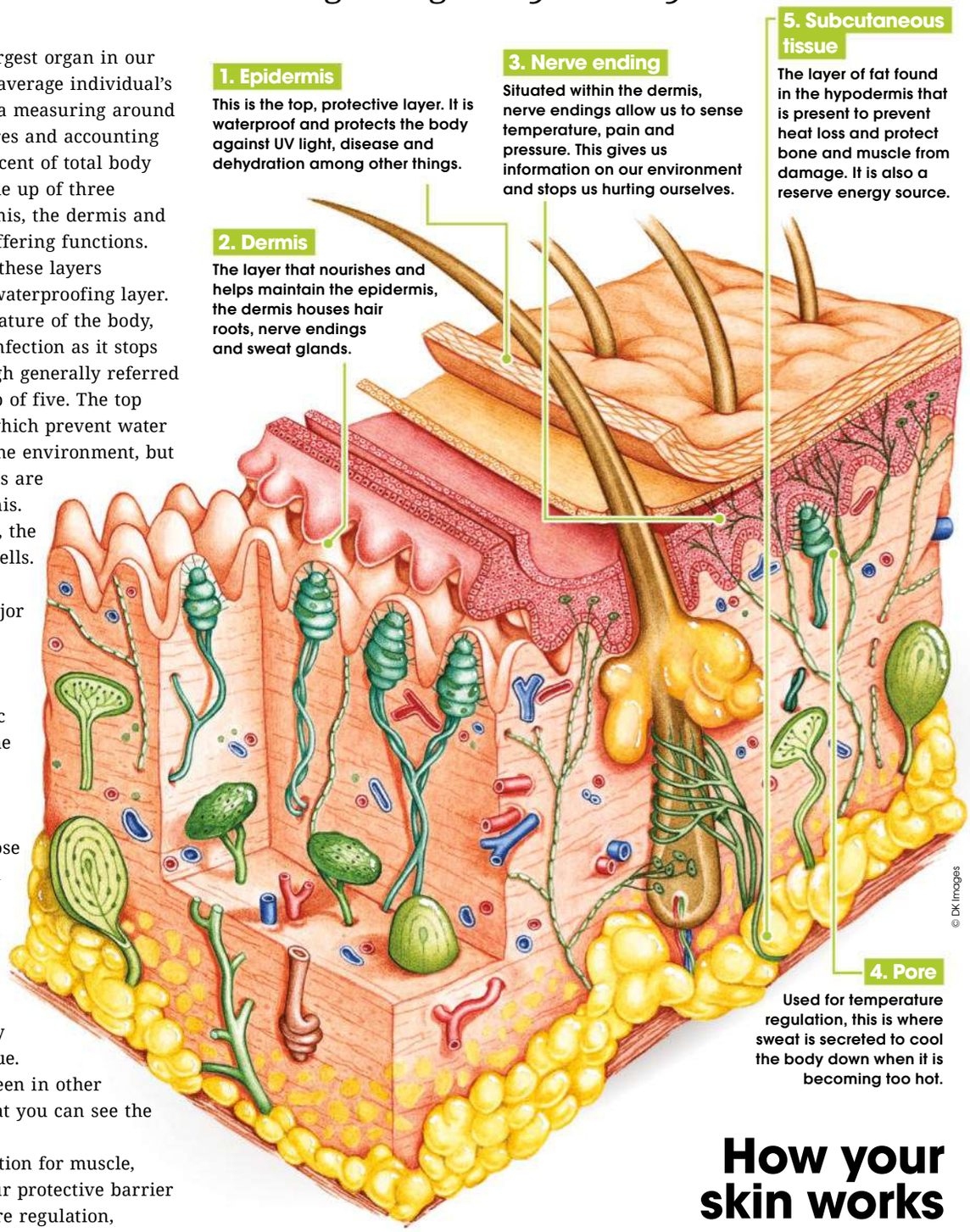
Find out more about the largest organ in your body...

Our skin is the largest organ in our bodies, with an average individual's skin surface area measuring around two square metres and accounting for up to 16 per cent of total body weight. It is made up of three distinct layers. These are the epidermis, the dermis and the hypodermis and they all have differing functions. Humans are rare in that we can see these layers distinctly. The epidermis is the top, waterproofing layer. Alongside helping to regulate temperature of the body, the epidermis also protects against infection as it stops pathogens entering the body. Although generally referred to as one layer, it is actually made up of five. The top layers are dead keratin-filled cells, which prevent water loss and provide protection against the environment, but the lower levels, where new skin cells are produced, are nourished by the dermis. In other species, such as amphibians, the epidermis consists of only live skin cells. In these cases, the skin is generally permeable and actually may be a major respiratory organ.

The dermis has the connective tissue and nerve endings, contains hair follicles, sweat glands, lymphatic and blood vessels. The top layer of the dermis is ridged and interconnects securely with the epidermis.

Although the hypodermis is not considered part of the skin, its purpose is to connect the upper layers of skin to the body's underlying bone and muscle. Blood vessels and nerves pass through this layer to the dermis. This layer is crucial for all of the skins temperature regulation, as it contains 50 per cent of a healthy adult's body fat in subcutaneous tissue. These kinds of layers are not often seen in other species, humans being one of few that you can see the distinct layers within the skin.

Not only does the skin offer protection for muscle, bone and internal organs, but it is our protective barrier against the environment. Temperature regulation, insulation, excretion of sweat and sensation are just a few more functions of skin.



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How your skin works

The skin is made of many more elements than most people imagine

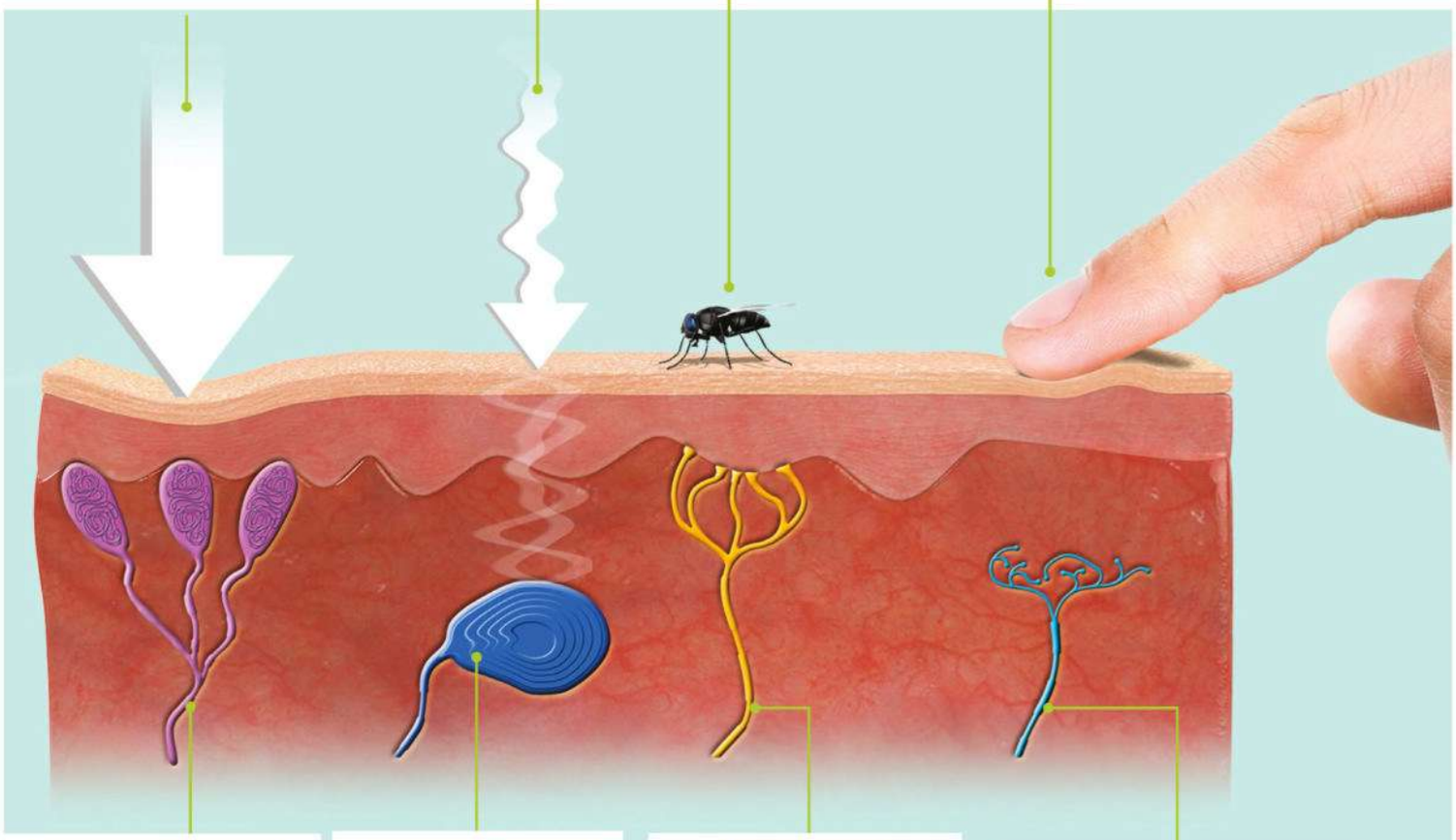
Skin senses

How does your skin pick up signals from the outside world?

The skin uses different detectors (called sensory receptors) to tell the difference between pressure and pain, hot and cold, and a light brush versus a hard poke. These receptors are specially adapted nerve endings, and many are wrapped in layers of tissue, helping them to function in various ways. They are located in different numbers across your body, with more in your hands, feet and lips than anywhere else. Some respond quickly before stopping, allowing you to grow accustomed to sensations that don't need constant monitoring, like the feeling of your clothes against your skin. Others are slow to stop signalling, so you remain aware of the sensation.

Under the skin

Different receptors take responsibility for detecting different aspects of touch



Meissner corpuscles
These sit in the bumps and ridges beneath the top layer of skin on the hands and the soles of the feet. They are sensitive to pressure and vibrations, which is useful for detecting texture.

Pacinian corpuscles
These are the largest of the sensory detectors in the skin. They sit deep below the surface, and are equipped to respond to fast vibration, deep pressure and tickles.

Merkel's discs
There are lots of these in the fingertips and lips, and they are good at sensing light pressure. They are particularly important for working out the shape and texture of objects.

Free nerve endings
Lots of the nerve endings under the skin aren't buried inside specific structures. These 'free' endings mainly detect pain, but some pick up on sensations such as pressure or temperature.

© SPL; Thinkstock

How wounds heal

It takes an army of cells to repair cuts and scrapes

Wound healing happens in four key stages: haemostasis, inflammation, proliferation and remodelling. Haemostasis means 'blood halting' in Greek, and is the first crucial part in closing a wound. The body's first line of defence when wounded is to constrict the blood vessels in the affected area to minimise blood loss. Platelets then start to stick to the exposed tissue, becoming activated and encouraging more and more platelets to clump together to plug the gap.

Once this plug is in place, a mesh of fibrin fibres starts to form around it, trapping passing blood cells and forming a sturdy clot that holds the wound closed until it can be repaired. This process only takes a matter of minutes, and once the bleeding stops, the local blood vessels dilate again, allowing immune cells to reach the area and begin the necessary repairs. This stage is called inflammation.

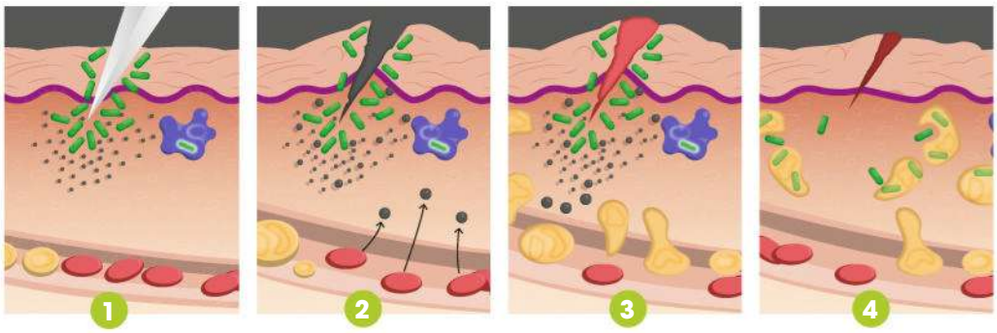
White blood cells clear up dead cells, get rid of damaged tissue and chase down any pathogens that have entered through the wound and destroy them by phagocytosis (ingesting them). They also prepare the area for the repair phase called proliferation.

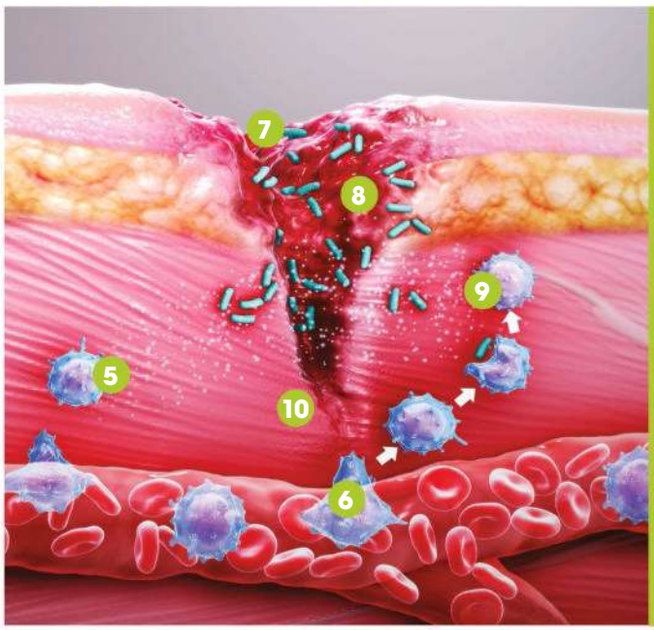
With the encouragement of the immune system, long, spindle-shaped cells called fibroblasts start rebuilding the collagen scaffolding that holds healthy tissue together. On top of the wound, epithelial cells begin dividing and migrating to cover the gap. New blood vessels start to form and, as the tissue heals, myofibroblasts tug at the edges of the wound to close the hole. Once this stage is complete, it's time for remodelling. The scaffolding built by the fibroblasts is rearranged, and any unneeded cells that were made during the healing process are safely removed.

> **"White blood cells clear up dead cells, get rid of damaged tissue and chase down any pathogens"**

Halting infection

The immune system rushes in to prevent pathogens entering through an open wound





1 Injury Blood vessels in the local area instantly constrict, reducing blood loss and limiting the chances of anything entering the bloodstream.

2 Clotting A plug of platelets starts to form. Clotting factors transform it into a strong network of fibres and trapped blood cells, barricading the breach.

3 Immune response Immune cells flood into the area, chasing down and killing any bacteria and cleaning away dead cells and damaged tissue.

4 Repair Immune cells encourage other cells to begin repairs. The support network under the skin is regenerated, and new cells grow over the wound.

5 Macrophage Macrophage means 'big eater'. These cells are the ones responsible for clearing away pathogens and debris.

6 Immune arrival Immune cells squeeze out of the blood vessels and into the tissue in a process called extravasation.

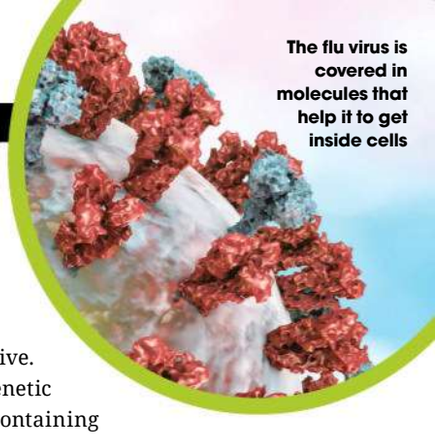
7 Granulation New tissue starts to form at the site of the injury. Although it is disordered at first, it gradually becomes more orderly.

8 Bacteria An open wound allows pathogens like bacteria to get inside the body.

9 Following the trails Immune cells are attracted to the site of the wound thanks to by a trail of chemical signals.

10 Scarring If the dermis (deep layer of skin) has been damaged, new collagen fibres form to mend it, creating a scar.

© SPL; Illustration by Ed Crooks



The flu virus is covered in molecules that help it to get inside cells

Bacteria vs virus

Which is which, and why does it even matter?

When you've got a sore throat, the cause doesn't always seem important. Some microscopic nasty is waging war with your immune system, it hurts, and you just want to feel better. But whether it's bacteria or a virus on the rampage is actually very important.

Bacteria are each made from just a single, primitive cell. Their insides are separated from the outside by a fatty membrane and a flexible coat of armour called the cell wall. Their genetic information is carried on loops of DNA, and these contain tiny factories called ribosomes, which use the genetic code to produce the molecules that the bacteria need to grow, divide and survive.

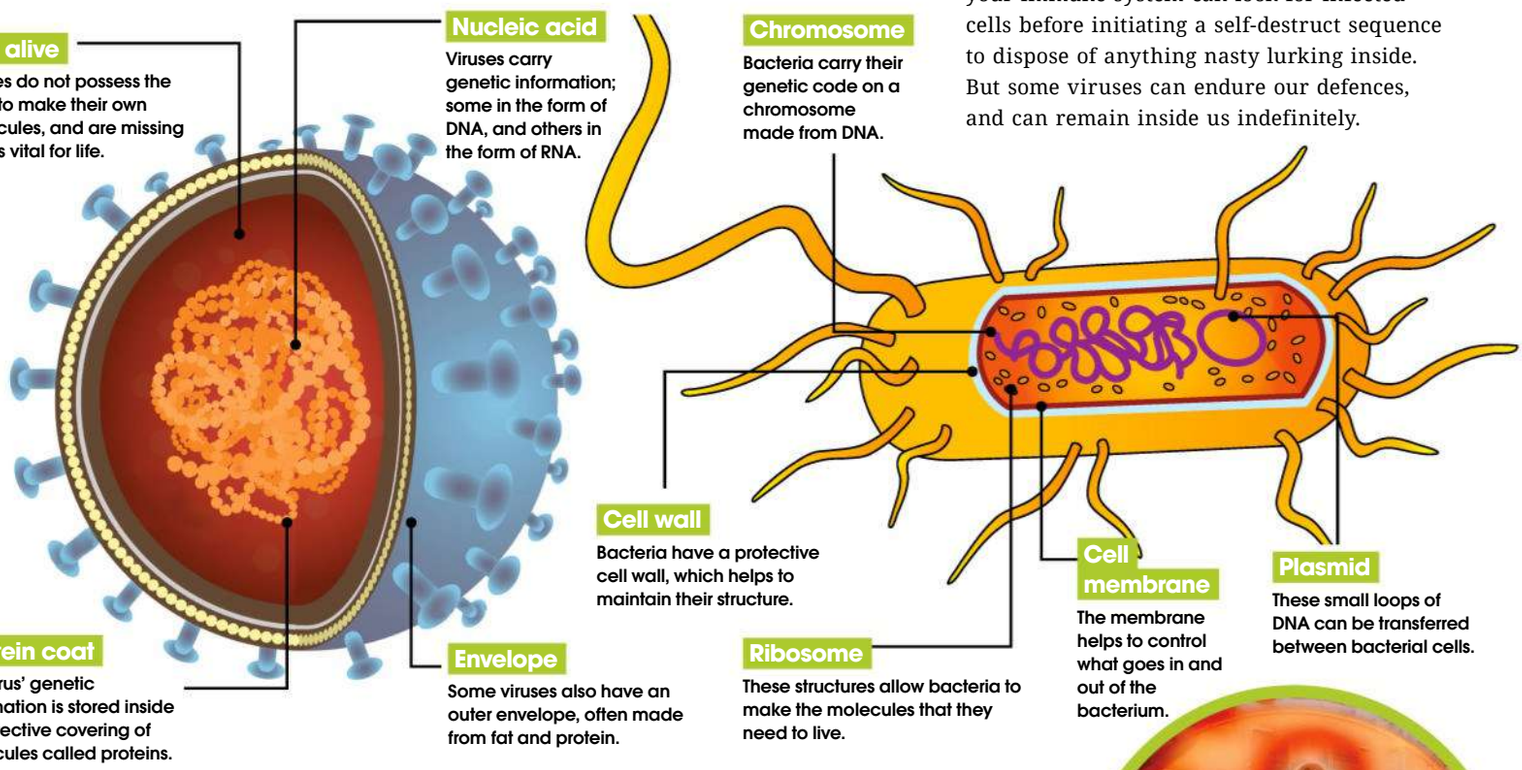
Viruses, on the other hand, are not technically alive. They carry genetic information containing the instructions to build more virus particles, but they don't have the equipment to make molecules themselves. To reproduce, they need to get inside a living cell and hijack its machinery, turning it into a virus factory.

Both bacteria and viruses can cause diseases, but knowing which is the culprit is critical to treating them. Antibiotics can harm bacteria, but do not effect viruses. Even your own immune system uses different tactics.

For bacteria, the immune system unleashes antibodies – weapons that stick invading microbes together, slowing them down and marking them for destruction. For viruses, your immune system can look for infected cells before initiating a self-destruct sequence to dispose of anything nasty lurking inside. But some viruses can endure our defences, and can remain inside us indefinitely.

Head to head

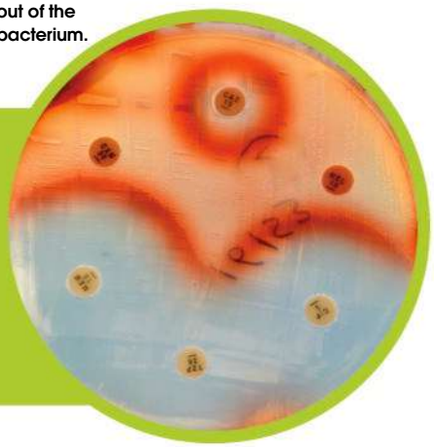
Both are microscopic, but take a closer look and the differences become clear



"For viruses to reproduce, they need to get inside a living cell and hijack its machinery, turning it into a virus factory"

Antibiotic resistance

Antibiotics attack bacteria. They work by interrupting the way that the tiny cells divide, grow and repair. However, if an infection is caused by a virus, antibiotics won't help. Viruses don't work in the same way as bacteria, so antibiotics can't help to fend them off. It might not seem like much of a problem, but every time antibiotics are used, it gives bacteria a chance to learn how to resist them. So every time a patient with a virus is given antibiotics, not only will they not get better, but bacteria lurking in their bodies will have a chance to see the drug and develop defences against it.



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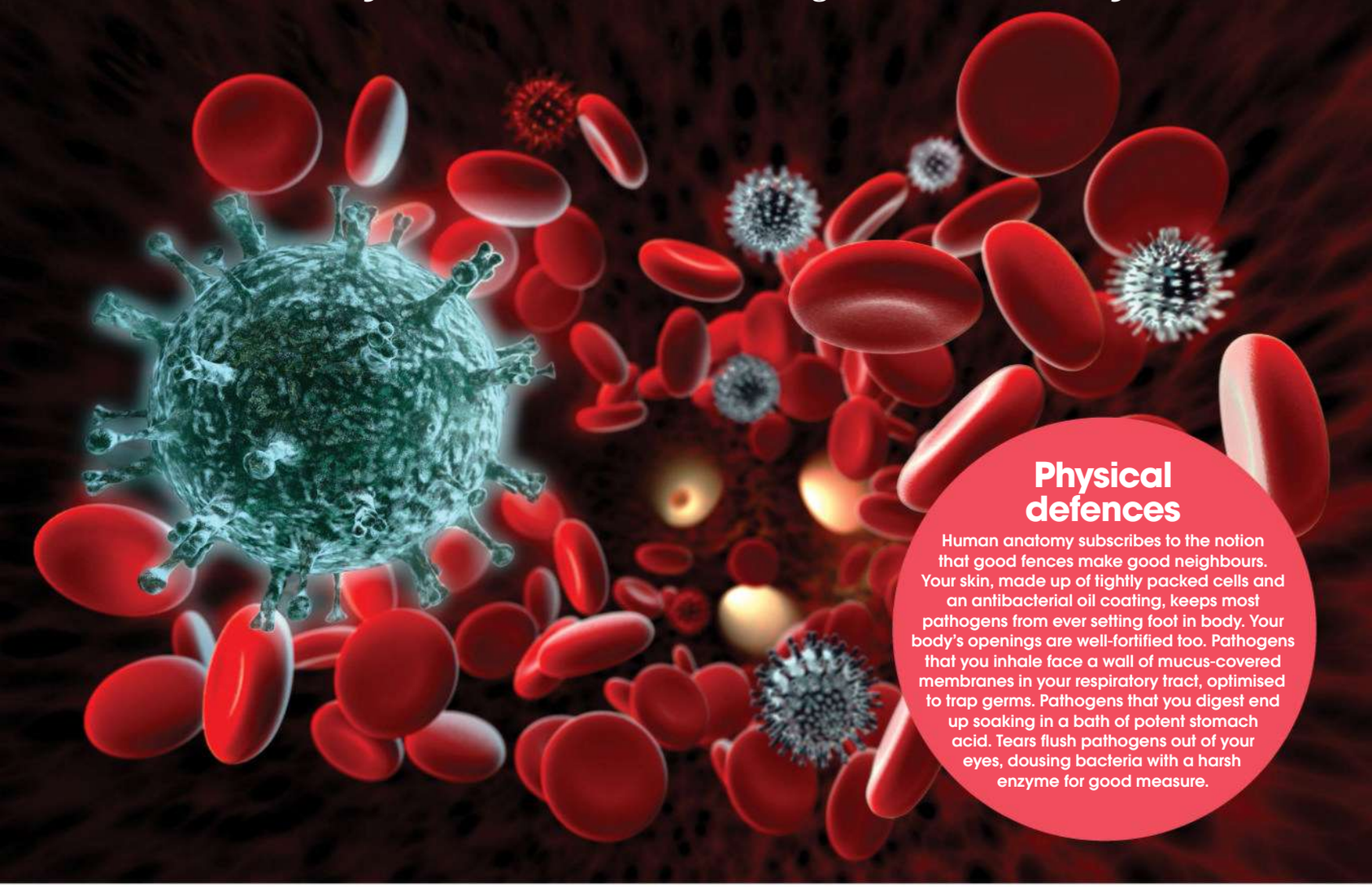
How your immune system works

Your body is locked in a constant war against a viscous army



Physical defences

Human anatomy subscribes to the notion that good fences make good neighbours. Your skin, made up of tightly packed cells and an antibacterial oil coating, keeps most pathogens from ever setting foot in body. Your body's openings are well-fortified too. Pathogens that you inhale face a wall of mucus-covered membranes in your respiratory tract, optimised to trap germs. Pathogens that you digest end up soaking in a bath of potent stomach acid. Tears flush pathogens out of your eyes, dousing bacteria with a harsh enzyme for good measure.

It's true: while you're simply sitting around watching TV, trillions and trillions of foreign invaders are launching a full scale assault on your cells. Collectively known as pathogens, these attackers include bacteria, single-celled creatures that live to eat and reproduce; protists, larger single-cell organisms; viruses, packets of genetic information that take over host cells and replicate inside them; and fungi, a type of plant life.

Bacteria and viruses are by far the very worst offenders. Dangerous bacteria release toxins in the body that cause diseases such as E. coli, anthrax, and the black plague. The cell damage from viruses causes measles, the flu and the common cold, among numerous other diseases.

Just about everything in our environment is teeming with these microscopic intruders, including you. The bacteria in your stomach alone outnumber all the cells in your body, ten-to-one. Yet, your microscopic soldiers usually win against pathogens, through a combination of sturdy barriers, brute force, and superior battlefield intelligence, collectively dubbed the immune system.

The adaptive immune system

Fighting the good fight, and white blood cells are right on the front line...

When a pathogen is tough, wily, or numerous enough to survive various non-specific defences, it's down to the incredibly adaptive immune system to clean up the mess. The key forces in the adaptive immune system are white blood cells which are called lymphocytes. Unlike their macrophage cousins, these lymphocytes are engineered to attack only one specific type of pathogen. There are two types of lymphocytes: B-cells and T-cells.

These cells join the action when macrophages pass along information about the invading pathogen, through chemical messages called interleukins. After engulfing a pathogen, a macrophage communicates details about the pathogen's antigens – telltale molecules that actually characterise particular pathogens. Based on this information, the immune system identifies specific B-cells and T-cells equipped to recognise and battle the pathogen. Once they are successfully identified, these cells rapidly reproduce, assembling an army of cells that are equipped to take down the attacker.

The B-cells flood your body with antibodies, molecules that either disarm a specific pathogen or bind to it, marking it as a target for other white blood cells. When T-cells find their target, they lock on and release toxic chemicals that will destroy it. T-cells are especially adept at destroying your body's cells that are infected with a dangerous virus.

This entire process takes several days or even weeks, with the raging battle causing you to feel terrible. Fortunately, the immune system is engineered to learn from the past. While your body is producing new B-cells and T-cells to fight the pathogens, it also produces memory cells – copies of the B-cells and T-cells, which stay in the system after the pathogen is defeated. The next time that pathogen shows up in your body, these memory cells help launch a counter-attack quickly, wiping out the invaders before infection takes hold – otherwise known as immunity. Vaccines work in the same way – exposing you just enough pathogen for you to develop memory cells, but not enough to make you sick.

Non-specific defences

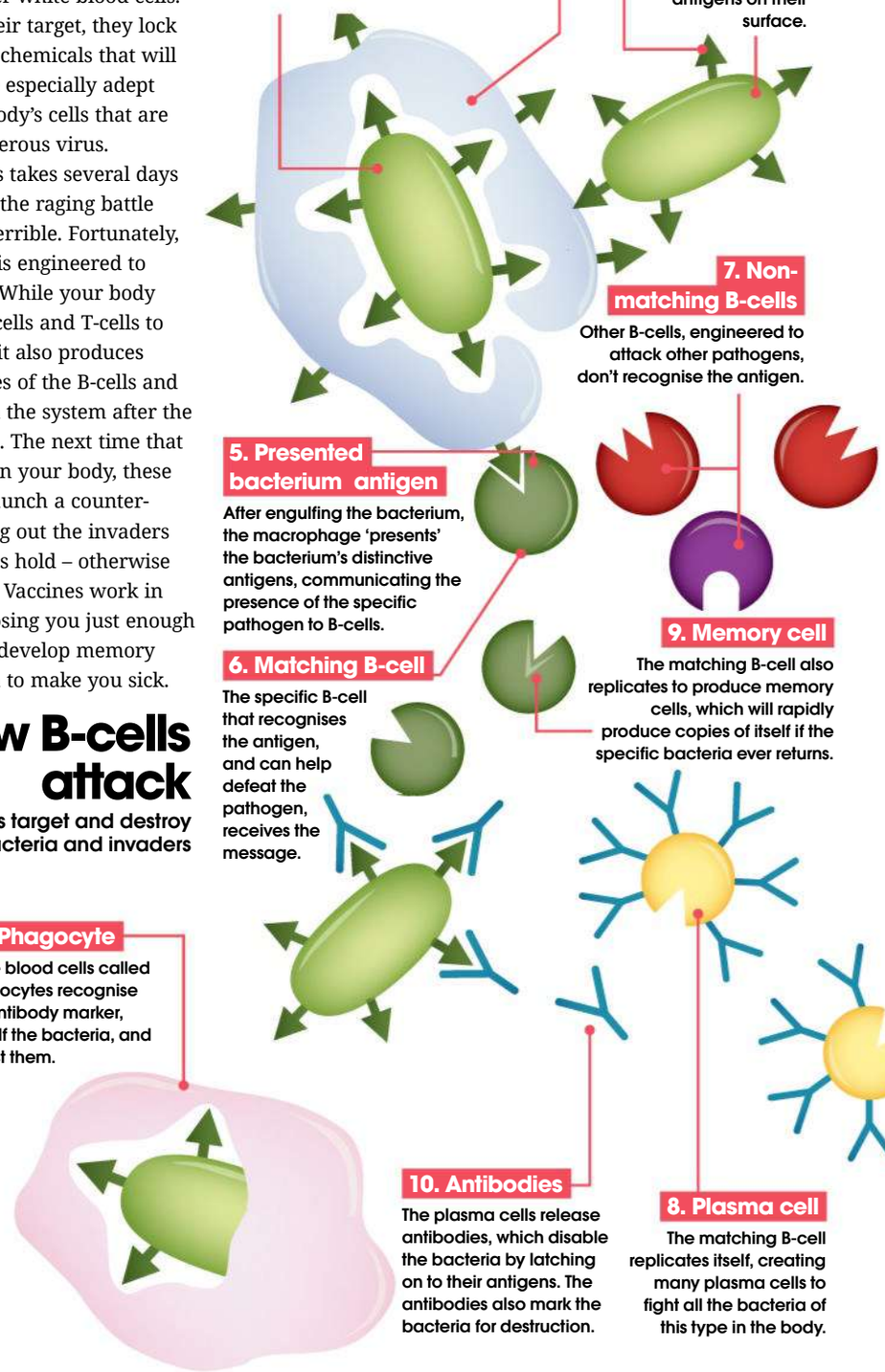
As good as your physical defence system is, pathogens often creep past it. Your body initially responds with counterattacks known as non-specific defences.

After a breech – a cut, for example – cells release chemicals called inflammatory mediators. This triggers the chief non-specific defence, known as inflammation. Within minutes of a breach, your blood vessels dilate, allowing blood and other fluid to flow into the tissue around the cut.

The rush of fluid in inflammation carries various types of white blood cells, which get to work destroying intruders. The biggest and toughest of the bunch are macrophages, white blood cells with an insatiable appetite for foreign particles. When a macrophage detects a bacterium's telltale chemical trail, it grabs the intruder, engulfs it, takes it apart with chemical enzymes, and spits out the indigestible parts. A single macrophage can swallow up about 100 bacteria before its own digestive chemicals destroy it from within.

How B-cells attack

B-cells target and destroy specific bacteria and invaders



Your tonsils can help fight bacteria

Disorders of the immune system

Who watches the watchmen?

The immune system is a powerful set of defences, so when it malfunctions, it can do as much harm as a disease. Allergies are the result of an overzealous immune system. In response to something that is relatively benign, like pollen for example, the immune system will trigger excessive measures to expel the pathogen. In extreme cases, allergies cause anaphylactic shock, which is a potentially deadly drop in blood pressure, sometimes accompanied by breathing difficulty and loss of consciousness. In autoimmune disorders such as rheumatoid arthritis, the immune system fails to recognise the body's own cells and attacks them.

In an allergic reaction, the body may resort to sneezing to expel a fairly harmless pathogen

Tonsils
Lymphoid tissue loaded with lymphocytes, which attack bacteria that get into the body through your nose or mouth.

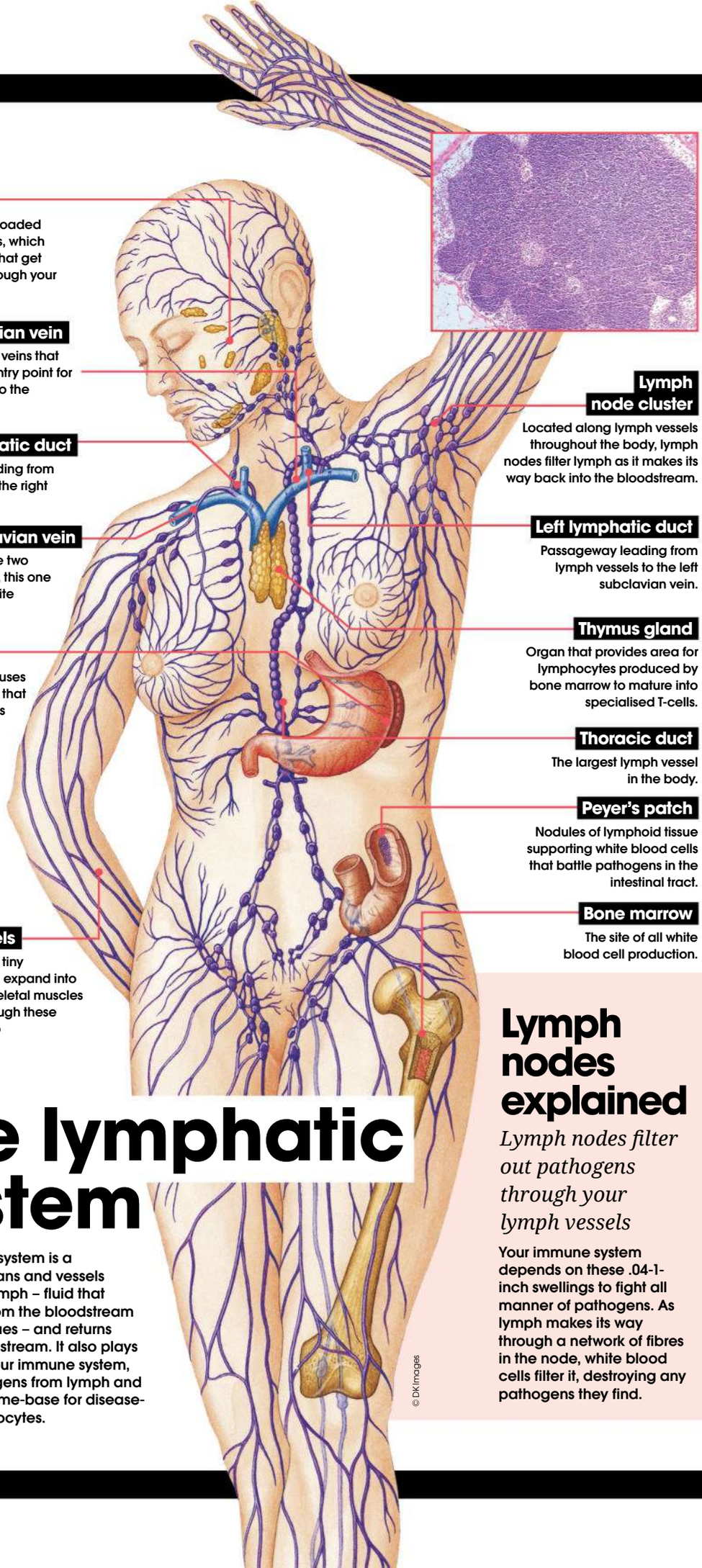
Left subclavian vein
One of two large veins that serve as the re-entry point for lymph returning to the bloodstream.

Right lymphatic duct
Passageway leading from lymph vessels to the right subclavian vein.

Right subclavian vein
The second of the two subclavian veins, this one taking the opposite path to its twin.

Spleen
An organ that houses white blood cells that attack pathogens in the body's bloodstream.

Lymph vessels
Lymph collects in tiny capillaries, which expand into larger vessels. Skeletal muscles move lymph through these vessels, back into the bloodstream.



Lymph node cluster
Located along lymph vessels throughout the body, lymph nodes filter lymph as it makes its way back into the bloodstream.

Left lymphatic duct
Passageway leading from lymph vessels to the left subclavian vein.

Thymus gland
Organ that provides area for lymphocytes produced by bone marrow to mature into specialised T-cells.

Thoracic duct
The largest lymph vessel in the body.

Peyer's patch
Nodules of lymphoid tissue supporting white blood cells that battle pathogens in the intestinal tract.

Bone marrow
The site of all white blood cell production.

The lymphatic system

The lymphatic system is a network of organs and vessels that collects lymph – fluid that has drained from the bloodstream into bodily tissues – and returns it to your bloodstream. It also plays a key role in your immune system, filtering pathogens from lymph and providing a home-base for disease-fighting lymphocytes.

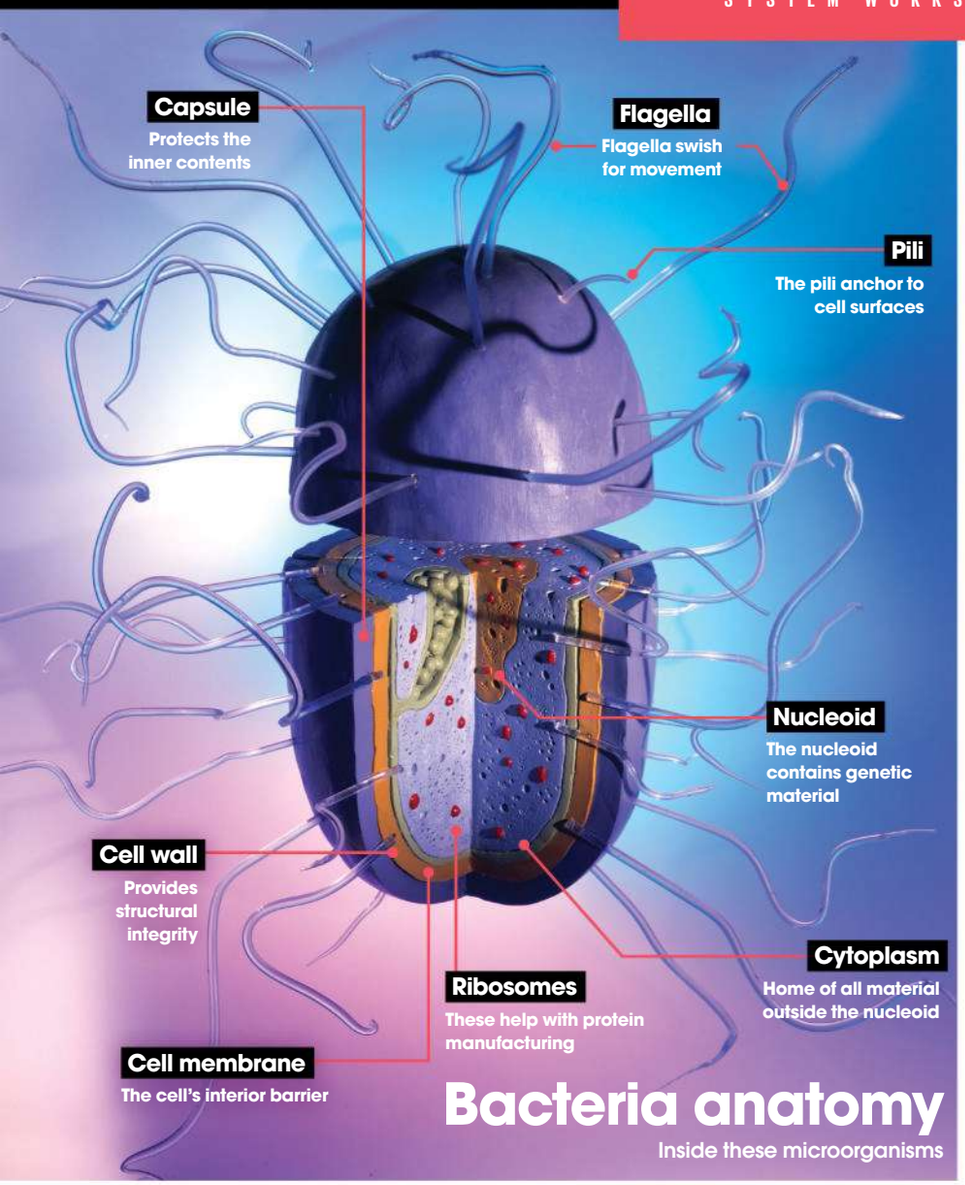
Lymph nodes explained

Lymph nodes filter out pathogens through your lymph vessels

Your immune system depends on these .04-1-inch swellings to fight all manner of pathogens. As lymph makes its way through a network of fibres in the node, white blood cells filter it, destroying any pathogens they find.

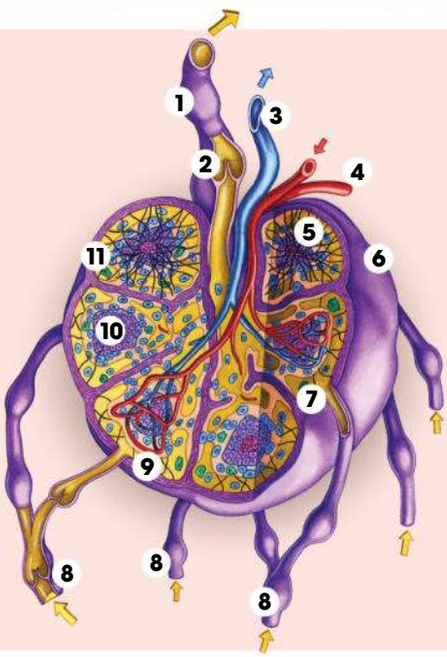
Know your enemy: Bacteria

Bacteria are the smallest and, by far, the most populous form of life on Earth. Right now, there are trillions of the single-celled



Bacteria anatomy

Inside these microorganisms



Major points of the lymph node

1. Outgoing lymph vessel
The vessel that carries filtered lymph out of the lymph node

2. Valve
A structure that prevents lymph from flowing back into the lymph node

3. Vein
Passageway for blood leaving the lymph node

4. Artery
Supply of incoming blood for the lymph node

5. Reticular fibres
Divides the lymph node into individual cells

6. Capsule
The protective, shielding fibres that surround the lymph node

7. Sinus
A channel that slows the flow of lymph, giving macrophages the opportunity to destroy any detected pathogens

8. Incoming lymph vessel
A vessel that carries lymph into the lymph node

9. Lymphocyte
The T-cells, B-cells and natural killer cells that fight infection

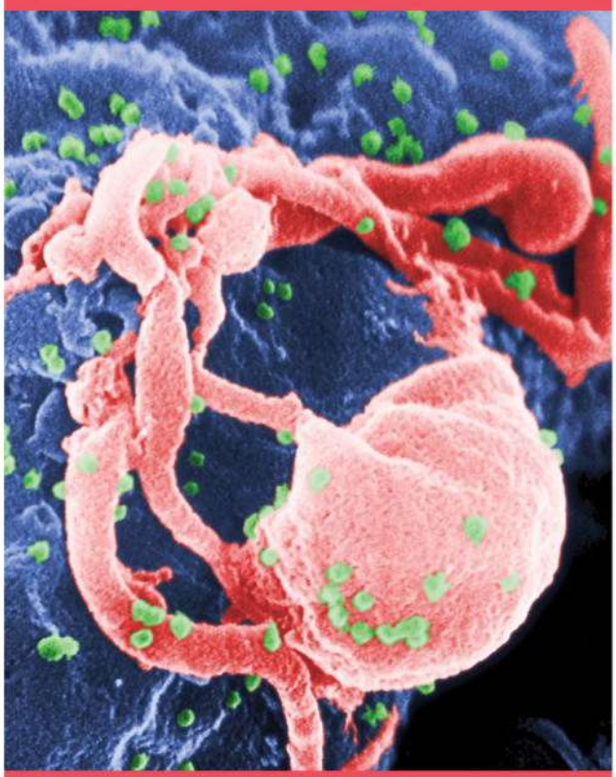
10. Germinal centre
This is the site of lymphocyte multiplication and maturation

11. Macrophage
Large white blood cells that engulf and destroy any detected pathogens

What is HIV...

... and how does it affect the immune system?

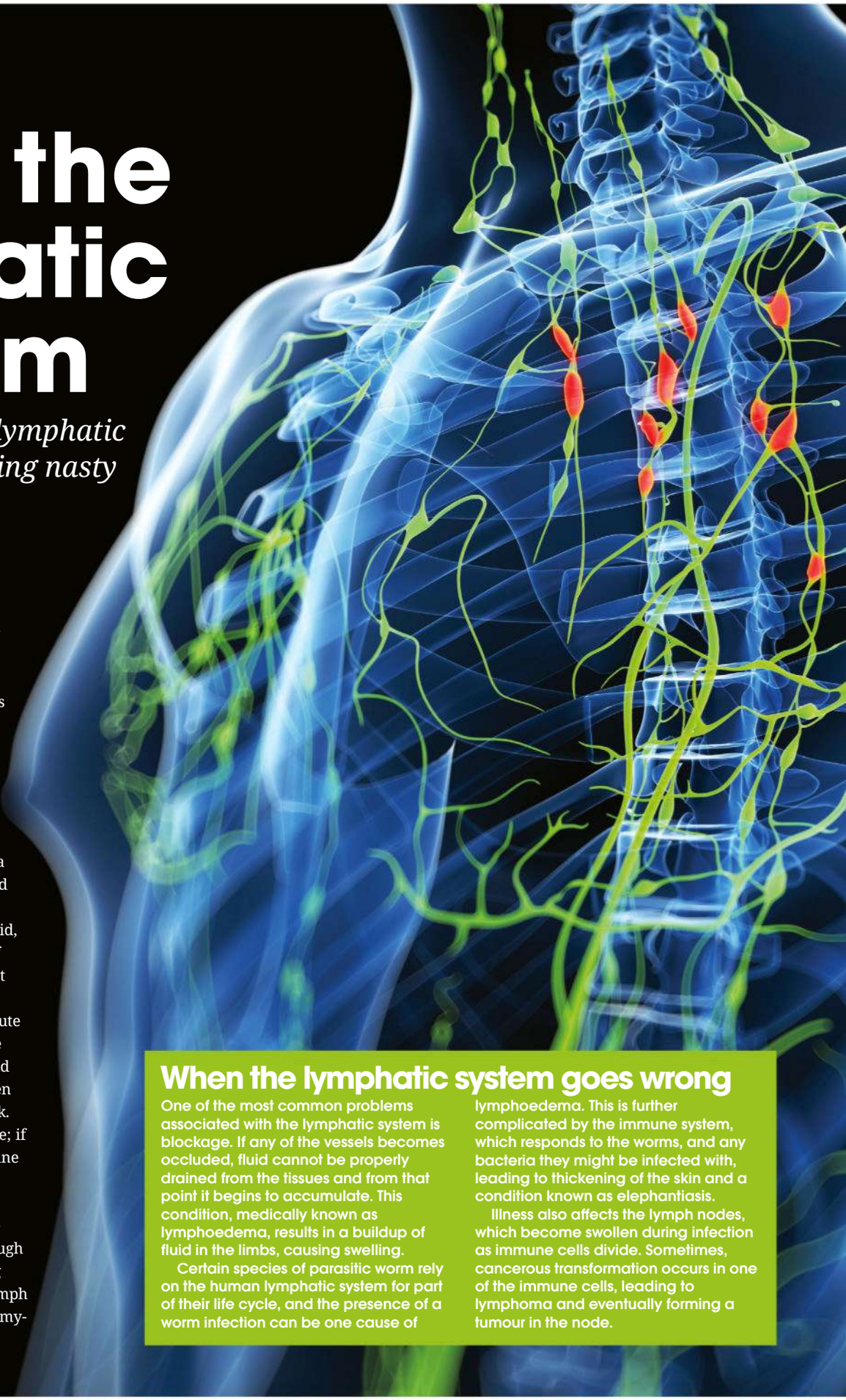
The human immunodeficiency virus (HIV) is a retrovirus (a virus carrying ribonucleic acid, or RNA as it's known), transmitted through bodily fluids. Like other deadly viruses, HIV invades cells and multiplies rapidly inside. Specifically, HIV infects cells with CD4 molecules on their surface, which includes infection-fighting helper T-cells. HIV destroys the host cell, and the virus copies go on to infect other cells. As the virus destroys helper T-cells, it steadily weakens the immune system. If enough T-cells are lost, the body then becomes highly susceptible to a range of different infections, a condition known as acquired immune deficiency syndrome (AIDS).



Scanning electron micrograph of HIV-1 budding (in green) from cultured lymphocyte. This image has been coloured to highlight the most important features. Multiple round bumps on the cell surface represent sites of assembly and budding of virions

Inside the lymphatic system

Learn what role our lymphatic system plays in keeping nasty bugs at bay



The red blood cells that carry oxygen around our bodies travel through blood vessels suspended in fluid known as plasma. It moves through vessels at such pressure that plasma can leak into the tissues. The lymphatic system helps remove it from the tissues and return it to the circulation.

The lymphatic system is similar to the circulatory system, in that it is composed of a series of vessels, found mostly in the skin and around internal organs. But the tubes do not make a circuit and there is no pump. The fluid, known as lymph, relies on the contraction of nearby muscles to return to the circulation at the subclavian veins near the collarbones.

The lymphatic system is also a transport route for the immune system. At intervals along the lymphatic vessels are between around 600 and 700 lymph nodes. Larger organs like the spleen and thymus are also connected to the network.

These organs manage immune surveillance; if an antigen-presenting cell (APC) of the immune system encounters a pathogen, it will return to the nearest lymph node with intel about the intruder. The specialist attack cells of the immune system, lymphocytes, circulate through the lymphatic system, scanning for matching patterns and, if one is found, they use the lymph node as a base to adapt until an army of enemy-specific clones is created.

When the lymphatic system goes wrong

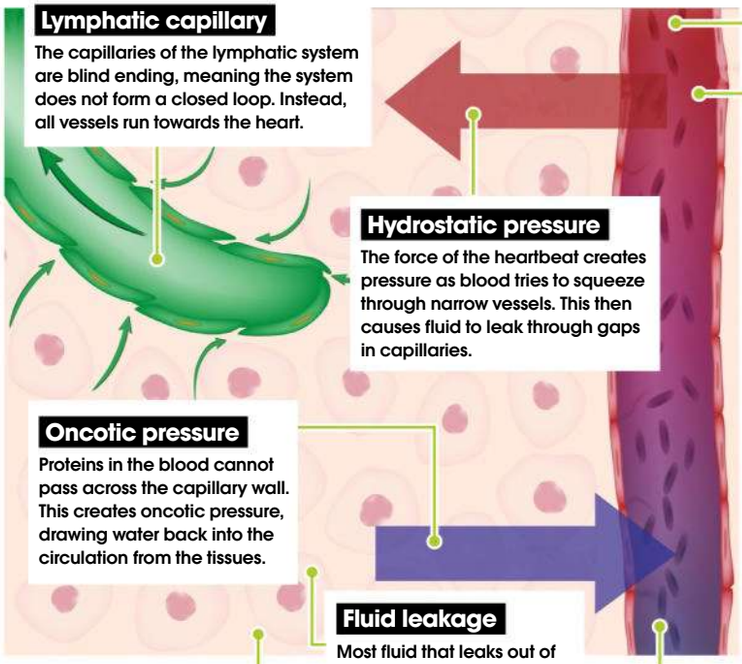
One of the most common problems associated with the lymphatic system is blockage. If any of the vessels becomes occluded, fluid cannot be properly drained from the tissues and from that point it begins to accumulate. This condition, medically known as lymphoedema, results in a buildup of fluid in the limbs, causing swelling.

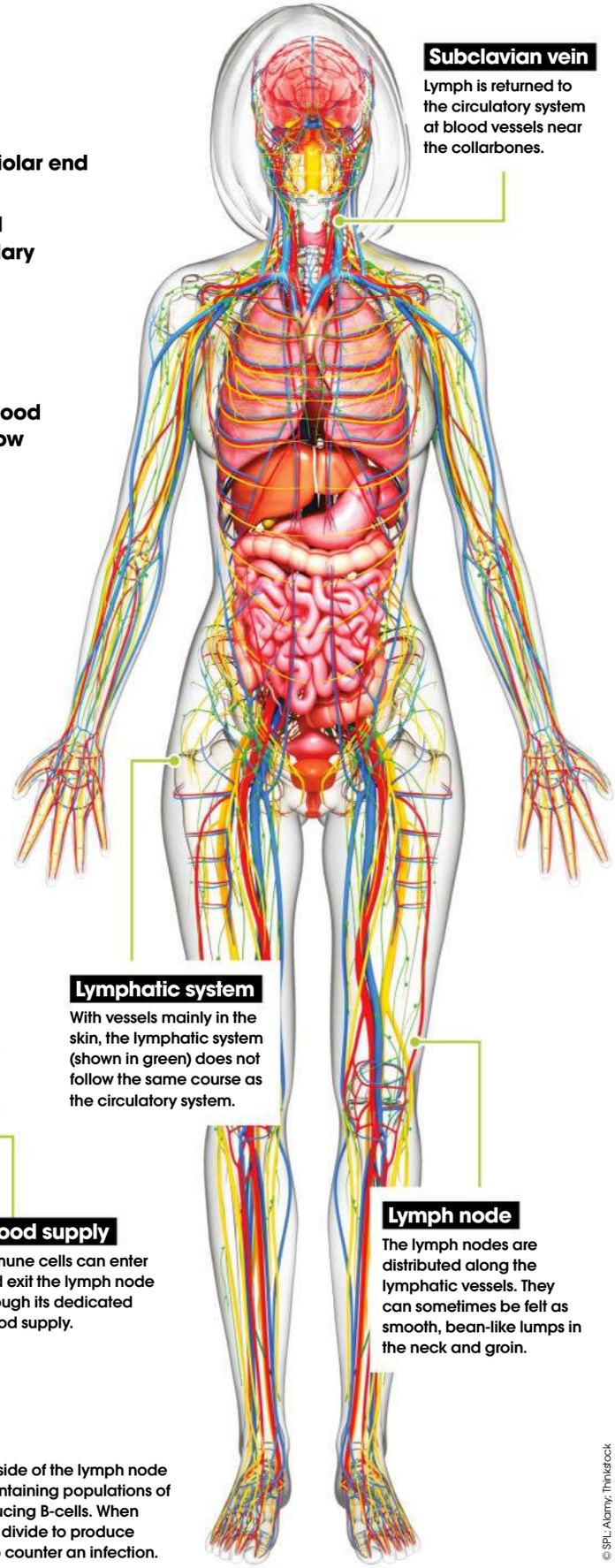
Certain species of parasitic worm rely on the human lymphatic system for part of their life cycle, and the presence of a worm infection can be one cause of lymphoedema. This is further complicated by the immune system, which responds to the worms, and any bacteria they might be infected with, leading to thickening of the skin and a condition known as elephantiasis.

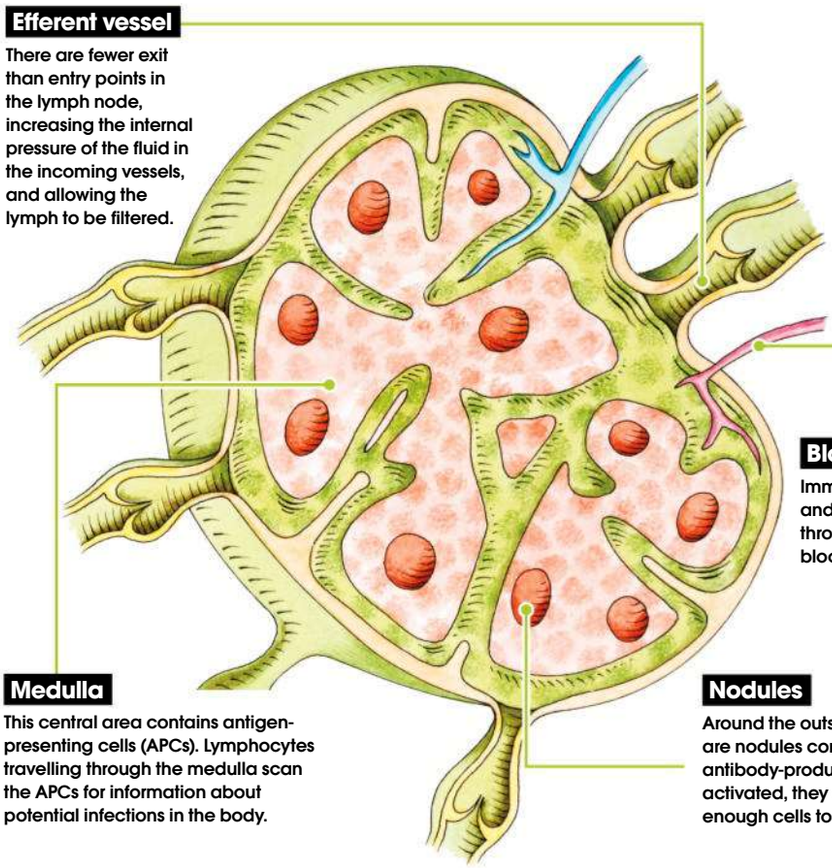
Illness also affects the lymph nodes, which become swollen during infection as immune cells divide. Sometimes, cancerous transformation occurs in one of the immune cells, leading to lymphoma and eventually forming a tumour in the node.

Capillary fluid exchange in action

See how lymph is transferred between the circulatory and lymphatic systems







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How do white blood cells work?

One of the body's main defences against infection and foreign pathogens, how do these cells protect our bodies?

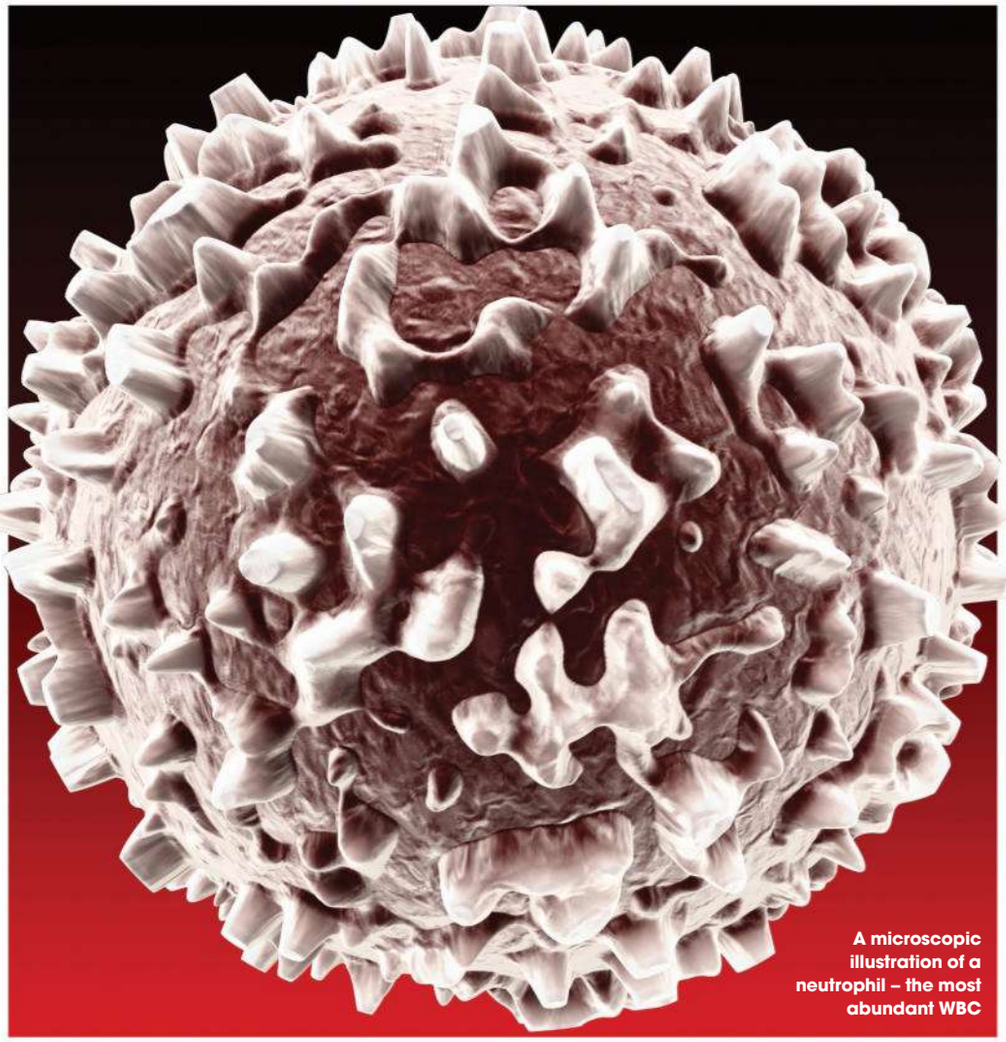
White blood cells, or leukocytes, are the body's primary form of defence against disease. When the body is invaded by a pathogen of any kind, the white blood cells attack in a variety of ways; some produce antibodies, while others surround and ultimately devour the pathogens whole.

In total, there are five types of white blood cell (WBC), and each cell works in a different way to fight a variety of threats. These five cells sit in two groupings: the granulocytes and the agranulocytes. The groups are determined based on whether a cell has 'granules' in the cytoplasm. These granules are digestive enzymes that help break down pathogens. Neutrophils, eosinophils and basophils are all granulocytes, the enzymes in which also give them a distinct colouration which the agranulocytes do not have.

As the most common WBC, neutrophils make up between 55 and 70 per cent of the white blood cells in a normal healthy individual, with the other four types (eosinophils, basophils, monocytes and lymphocytes) making up the rest. Neutrophils are the primary responders to infection, actively moving to the site of infection following a call from mast cells after a pathogen is initially discovered. They consume bacteria and fungus that has broken through the body's barriers in a process called phagocytosis.

Lymphocytes – the second-most common kind of leukocyte – possess three types of defence cells: B cells, T cells and natural killer cells. B cells release antibodies and activate T cells, while T cells attack diseases such as viruses and tumours when directed, and regulatory T cells ensure the immune system returns to normal after an attack. Natural killer cells, meanwhile, aid T cell response by also attacking virus-infected and tumour cells, which lack a marker known as MHC.

The remaining types of leukocyte release chemicals such as histamine, preparing the body for future infection, as well as attacking other causes of illness like parasites.



A microscopic illustration of a neutrophil – the most abundant WBC

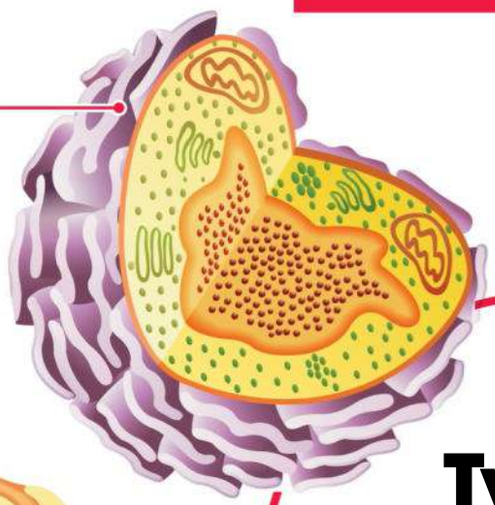
A faulty immune system

If the immune system stops working properly, we are at risk of becoming ill. However, another problem is if the immune system actually goes into overdrive and starts attacking the individual's own cells, mistaking them for pathogens. There are a large number of autoimmune ailments seen across the world, such as Crohn's disease, psoriasis, lupus and some cases of arthritis, as well as a large number of diseases that are suspected to have autoimmune roots.

We can often treat these conditions with immunosuppressants, which deactivate elements of the immune system to stop the body attacking itself. However, there are drawbacks with this treatment as, if the person exposes themselves to another pathogen, they would not have the normal white blood cell response. Consequently, the individual is less likely to be able to fight normally low-risk infections and, depending on the pathogen, they can even be fatal.

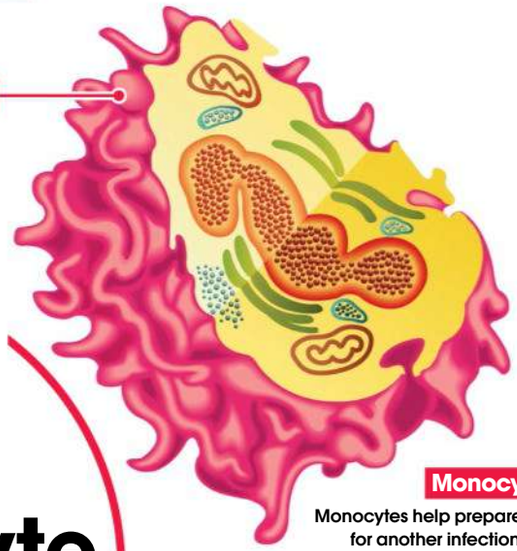
Types of leukocyte

Different kinds of WBC have different roles, which complement one another to defend the body



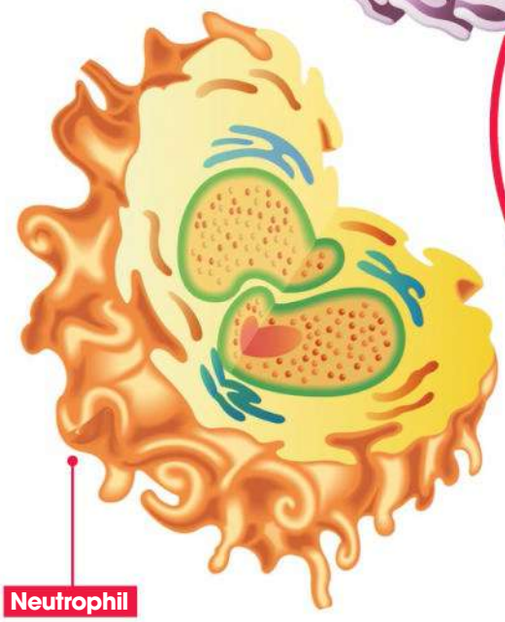
Basophil

Basophils are involved in allergic response via releasing histamine and heparin into the bloodstream. Their functions are not fully known and they only account for 0.4 per cent of the body's white blood cells. Their granules appear blue when viewed under a microscope.



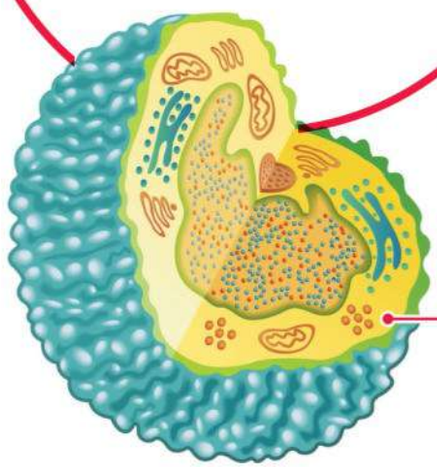
Eosinophil

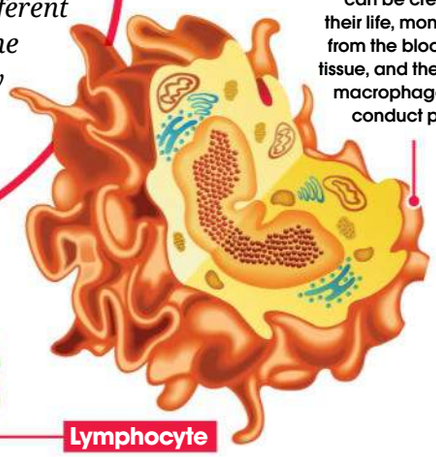
Eosinophils are the white blood cells that primarily deal with parasitic infections. They also have a role in allergic reactions. They make up a fairly small percentage of the total white blood cells in our body – about 2.3 per cent.



Neutrophil

Neutrophils are the most common of the leukocytes. They have a short life span so need to be constantly produced by the bone marrow. Their granules appear pink and the cell has multi-lobed nuclei which make them easily differentiated from other types of white blood cell.





Monocyte

Monocytes help prepare us for another infection by presenting pathogens to the body, so that antibodies can be created. Later in their life, monocytes move from the bloodstream into tissue, and then evolve into macrophages which can conduct phagocytosis.

Lymphocyte

These release antibodies as well as attack virus and tumour cells through three differing types of cell. As a group, they are some of the longest lived of the white blood cells with the memory cells surviving for years to allow the body to defend itself if repeat attacks occur.

White blood cells at work

The body has various outer defences against infection, including the external barrier of the skin, but what happens when this is breached?

Skin breach

A foreign object breaks through the skin, introducing bacteria (shown in green) into the body.

Mast cells

Mast cells release cytokines and then WBCs are called into action to ensure the infection does not spread.

WBCs arrive

Macrophages move to the site via the bloodstream to start defending against invading bacteria.

Macrophages consume bacteria

Bacteria are absorbed into cytoplasm and broken down by the acrophages.

Healing

Following removal of the bacteria, the body will start to heal the break in the skin to prevent further infection.

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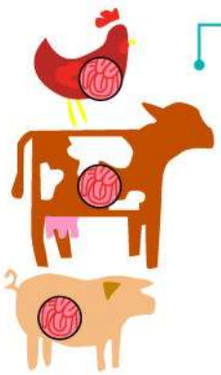
The war against superbugs

Learn how bacteria will hide, change, lie and cheat to evade antibiotics and secure their survival

Bacteria are vital to our survival. They help us digest food and help develop our advanced immunity while we're young. However, they can also cause diseases. Antibiotics were discovered in 1928 and almost overnight they changed what were once fatal diseases into trivial infections. But despite effective medication, bacteria are smart and know how to fight back. They can change their shape, hide in plain sight and alter their surface appearance. After an attack from antibiotics, the few bacteria left over are the strongest of the bunch and are resistant to the current crop of antibiotics; this is true survival of the fittest. The lasting bacteria then multiply, become stronger and are able to survive attacks from other antibiotics. This is known as 'multidrug resistance' and has led to certain bacteria being ominously called 'superbugs.' Over the last 30 years, too many antibiotics have been prescribed, contributing to this resistance. This is why doctors no longer give antibiotics for simple colds; they have no effect on viruses but can contribute to antibiotic resistance.

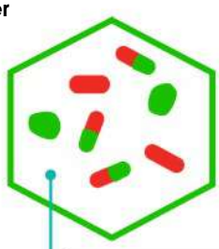
The revenge of the superbug

How the toughest bacteria are taking over



Bottom of the food chain

Many farm animals are given antibiotics to keep them healthy. They subsequently develop resistant bacteria in their guts.

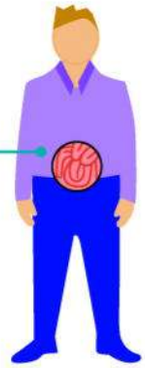


Realm of the superbug

The remaining bacteria are now resistant to even the strongest antibiotics and are called superbugs. They spread as patients move and on healthcare staff who go between patients.

Resistance in humans

Antibiotics given for simple illnesses lead to resistance in healthy people.



Entering our food chain

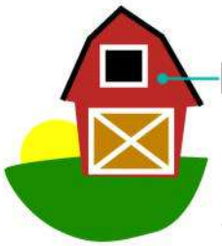
The resistant bacteria in food and vegetables can remain in the human gut once we've eaten them.

Entering hospitals

As patients enter and leave hospitals, these tough bugs start growing in wards and nursing homes.

Community resistance

Community resistance gradually develops, helping the toughest bacteria to establish and spread.

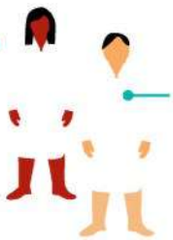


Crop circles

Fertiliser used on crops contains animal matter, which also contains the resistant bacteria, increasing their spread.

Weak targets

They cause infections, secondary to the main reason the patient is in hospital. Doctors treat these, but some bacteria still remain.



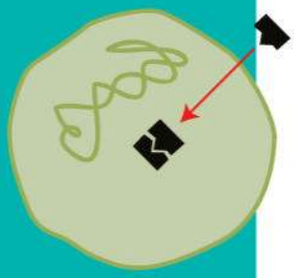
Future strategies

Doctors only prescribe antibiotics for as short a time as possible. New and smarter antibiotics tackle even the toughest of resistance.

How antibiotic resistance develops

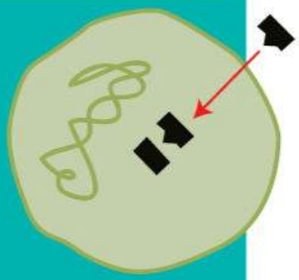
Normal function

Antibiotics target bacterial cells, by changing the signals of their outer wall, their membrane shape, impairing DNA function in the cell or by blocking protein synthesis.



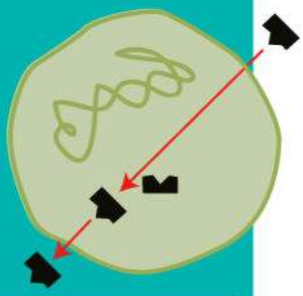
Changing the landing zone

Bacteria can change the shape and structure of the molecules that antibiotics target, meaning they can't recognise them and therefore rendering them useless.



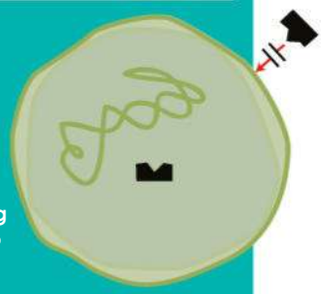
One in, one out

Antibiotics enter bacterial cells via special pumps. The bacteria can develop more exit than entry pumps, meaning the antibiotic is forced through an exit faster than it can enter.



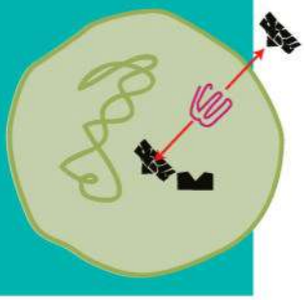
Entry policy

Bacteria can stop antibiotics entering: they can change the shape of entry pumps and reduce the size of pores in their surface, meaning the antibiotics are too large to enter.



Inactivation

The strongest bacteria develop special enzymes, which can destroy the key parts of an antibiotic before they have a chance to take effect.



UNDERSTANDING Human Anatomy

Future PLC Quay House, The Ambury, Bath, BA1 1UA

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Printed in the UK

Distributed by Marketforce – www.marketforce.co.uk
For enquiries, please email: mfcommunications@futurenet.com

Understanding Human Anatomy Second Edition (HIB6368)
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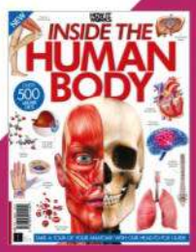

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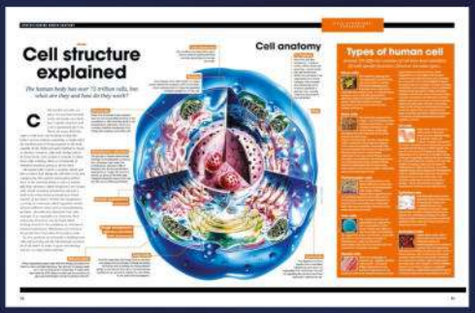

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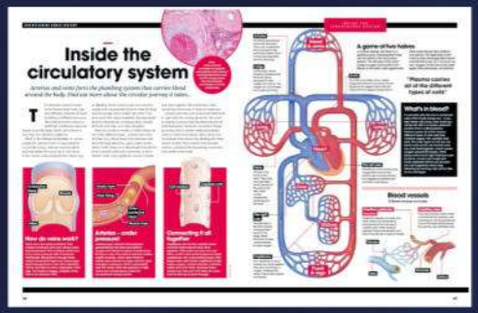

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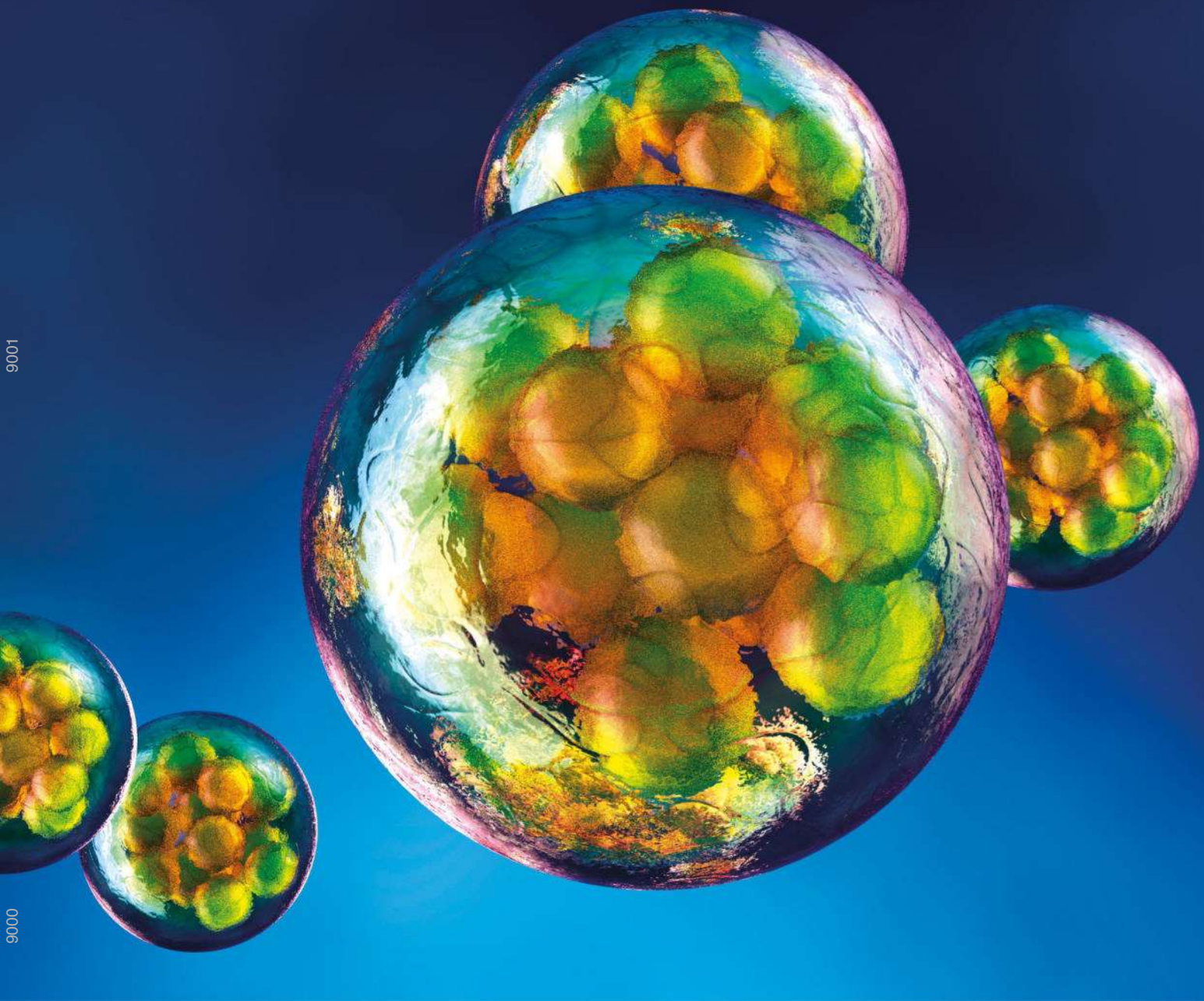

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